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FIBRES USED IN TEXTILE AND
ALLIED INDUSTRIES

FIBRES
USED IN
TEXTILE AND ALLIED
INDUSTRIES

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PREFACE.

FOR many years past both the writers have been independently engaged in the technical examination of fibres, and much of their experience is embodied in the following pages.

The descriptions of the methods needed for this kind of work are, for the most part, contained in different scientific publications, and in the present book an attempt is made to bring together in a form convenient for use in the laboratory both the microscopical and chemical technical methods.

The book deals with the principal fibres that are used in what for want of a better term may be called the "isolated" condition. That is to say, it includes fibres used in a more or less dissociated condition in spinning, weaving, cordage, brush-making and upholstery, but does not include furriery or paper-making.

With three exceptions, every illustration has been drawn specially for the book directly from the fibres, and our endeavour has been to make them as recognisable as possible. Hence they have not been represented in a diagrammatic form, nor has undue prominence been given to special features of interest as in some of the microscopical text-books. As far as possible they have all been drawn to the same scale (a mag-

nification of 104 diameters) as an aid to rapid comparison.

In this connection it gives us great pleasure to acknowledge our indebtedness to Mr. G. Tattersfield (of Messrs. Tattersfield & Co., of Bradford), who has taken great trouble to procure for us genuine specimens of every kind of wool. The whole of the illustrations of wool and allied fibres have been drawn from these samples.

We also desire to thank Messrs. Cohen & Son and Messrs. Brocklehurst & Sons for specimens of silk of known origin, and Mr. S. Neugass for samples of commercial ramie, polished cotton and Chardonnet silk.

Specimens of artificial silk were also kindly supplied by the Furst Guido Co., of Stettin, and by the Soc. de la Soie Artificielle Linkmeyer, while we have to thank the Lyxhayr Co. for samples of their excellent substitute for horse hair.

We have duly acknowledged in the footnotes the assistance given us by various publications, and would mention in particular the works of Messrs. Cross & Bevan, whose researches form the essential basis of most of the chemical methods now used in the technical examination of fibres.

C. A. M.

R. M. P.

LONDON, *August*, 1910.

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CHAPTER I.

INTRODUCTION.

Classification of Fibres—General Characteristics of Fibres—General Methods of Examination

Classification of Fibres.—Fibres used for industrial purposes fall naturally into the three groups: mineral, animal and vegetable fibres, which may easily be distinguished from one another.

Mineral Fibres.—Apart from finely spun glass, slag wool, and the metal threads used for embroidery and similar purposes, the only representatives of this group are the different varieties of asbestos.

The fibres of asbestos are relatively long and often of extreme fineness, and are very soft and lustrous, though lacking in strength. For spinning or weaving they are usually mixed with a vegetable fibre which is subsequently removed by ignition.

Asbestos consists in the main of magnesium silicate and calcium silicate, with smaller quantities of other constituents.

Animal Fibres.—The animal fibres used in the textile and allied industries are either hairs from various animals, or the silk produced by the silkworm and the larvae of other moths. Most of the hair fibres woven into textile materials are derived from sheep, goats and camels, though the hair of many other animals is also used to a limited extent.

Animal fibres may be distinguished from vegetable fibres both by their appearance under the microscope, and by their different chemical composition.

Whereas vegetable fibres consist principally of cellulose or a compound of cellulose, animal fibres are composed in the main

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of protein substances (which in the case of wool contain sulphur).

Hence, on igniting the fibres they curl up and emit an odour of burnt horn quite distinct from the odour of burnt wood given off by burning vegetable fibres.

Various chemical methods of distinguishing between animal and vegetable fibres are described under the sections dealing with wool, silk and cotton.

For the differentiation of the various animal fibres from one another reliance must be placed chiefly upon the microscope.

Vegetable Fibres.—The following arrangement of vegetable fibres used for technical purposes has been based by Wiesner mainly on differences of botanical origin:—

A. VEGETABLE HAIRS.

Cotton (seed-hairs of various species of *Gossypium*).

Fibres of "cotton trees" (*Bombax* cottons).

Vegetable silks (seed hairs of *Asclepiadaceæ*, etc.).

B. BAST FIBRES FROM STEMS OF DICOTYLEDONOUS PLANTS.

(a) *Flax and Flax-like Fibres.*

Flax (*Linum usitatissimum*).

Hemp (*Cannabis sativa*).

Ganbo hemp (*Hibiscus cannabinus*).

Sunn hemp (*Crotalaria juncea*).

Fibre of *Sida refusa*.

Yercum fibre (*Calotropis gigantea*).

(b) *Boehmeria Fibres.*

Ramie or China grass (*Boehmeria juncea*).

(c) *Jute and Jute-like Fibres.*

Jute (*Corchorus capsularis* and *C. olitorius*).

Fibre of *Abelmoschus tetraphylla*.

 ,, *Urena sinuata*.

(d) *Coarse Bast Fibres.*

Bast fibres of *Bauhinia racemosa*.

 ,, ,, *Thespesia lampas*.

 ,, ,, *Cordia latifolia*.

(e) *Basts.*Bast of Linden (*Tilia* species).

”	”	<i>Sterculia villosa.</i>
”	”	<i>Holoptelia integrifolia.</i>
”	”	<i>Kydia calycina.</i>
”	”	<i>Lasiosiphon speciosus.</i>
”	”	<i>Sponia Wightii.</i>

C. FIBRE BUNDLES OF MONOCOTYLEDONOUS PLANTS.

(a) *Leaf Fibres.*

Manila hemp (fibres of *Musa textilis* and other *Musa* fibres).
 Pita fibre (*Agave americana*).
 Sisal hemp (*A. riijida*).
 Mauritius hemp (*Fuicrora gigantea*).
 New Zealand flax (*Phormium tenax*).
 Aloe fibres (from species of *Aloes*).
 Bromelia fibres (from species of *Bromelia*).
 Pandanus fibres (from species of *Pandanus*).
 Sansevieria fibre (from species of *Sansevieria*).
 Esparto fibre (*Stipa tenacissima*).
 Piassava (*Attalea funifera*, *Raphia vinifera*, etc.).

(b) *Stem Fibres.*

Tillandsia fibre.

(c) *Fruit Fibres.*

Coir (*C. nucifera*).

Peat fibre.

(d) *Paper Fibres.*

Straw, esparto, bamboo, wood pulp, bast fibre of paper mulberry, etc.

Dodge¹ classifies vegetable fibres into the following groups in accordance with their use in the plant economy and their relation to the part of the plant:—

¹ “Useful Fibre Plants of the World,” p. 25.

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A. FIBRO-VASCULAR STRUCTURE.

1. *Bast Fibres.*

Derived from the inner fibrous bark of dicotyledonous plants or exogens, or outside growers. Composed of bast cells overlapping to form a filament. They occupy the phloem portion of the fibro-vascular bundles, and their utility is to give strength and flexibility to the tissue.

2. *Woody Fibres.*

- (a) The stems and twigs of exogenous plants simply stripped of their bark and used entire or split into withes for weaving or plaiting into baskets.
- (b) The entire or sub-divided roots of exogenous plants used for the same purpose, or as coarse thread.
- (c) The wood of exogenous trees easily divided into splints, used for the same purposes or as fine packing material.
- (d) The wood of certain soft exogenous trees which is converted into wood pulp.

3. *Structural Fibres.*

- (a) Derived from the structural system of the stalks, leaf-stems, leaves, etc., of monocotyledonous plants or inside growers, occurring as isolated fibro-vascular bundles and surrounded by a pithy, cork-like, or soft cellular mass covered with a thick epidermis. They give to the plant rigidity and toughness, enabling it to resist injury, and they also serve as water vessels.
- (b) The whole stems, roots or leaves, or split and shredded leaves of monocotyledonous plants.
- (c) The fibrous portion of the leaves or fruits of certain exogenous plants when deprived of their epidermis and soft cellular tissue.

B. SIMPLE CELLULAR STRUCTURE.

4. *Surface Fibres.*

- (a) The down or hair on seeds or seed envelopes of exogenous plants, which are usually contained in a capsule or pod.
- (b) Hair-like growths found on the surfaces of the stems and leaves or leaf buds of both divisions of plants.
- (c) Fibrous material produced in the form of epidermal strips from the leaves of certain endogenous species, e.g., the palms

5. *Pseudo-fibres, or false fibrous material*

- (a) Certain mosses (e.g., species of *Sphagnum*), used as packing material.
- (b) Certain leaves and marine weeds which are dried and used as packing material.
- (c) Seaweeds made into lines or cordage.
- (d) Fungous growths (mycelia of certain fungi).

Economic Classification of Fibres.—Dodge¹ gives the following classification of vegetable fibres in accordance with their economic uses:—

A. SPINNING FIBRES

1. *Fabric Fibres*

- (a) Fibres of first rank for spinning fabrics for wearing apparel, awnings, sails, etc.
[Cotton, flax, ramie, hemp, pine apple, New Zealand flax.]
- (b) Fibres of second rank used for bagging, woven matting, floor coverings, etc.
[Jute, coir]

2. *Netting Fibres.*

- (a) Lace fibres—including cotton, flax, ramie, agave, etc.
“Useful Fibre Plants of the World,” p. 31.

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- (b) Coarse netting fibres—used for nets and hammocks.
 - [Cotton, flax, ramie, agave, etc., and innumerable native fibres from tree basts, palms, etc.]
- 3. *Cordage Fibres.*
 - (a) Fine spun threads and yarns used for cordage, twines, etc.
 - [All the commercial fabric fibres, Sunn, Mauritius and bowstring hems, New Zealand flax, and the commercial hard fibres, coir, manila and sisal hems, etc.]
 - (b) Rope and cables. [Chiefly hemp, sisal and manila hems, and native fibres from palms, etc.]

B. TIE MATERIAL (*rough twisted*).

Very coarse material such as stripped palm leaves, peeled bark of trees used without preparation as emergency cordage, etc.

C. NATURAL TEXTURES.

- 1. *Tree basts with tough interlacing fibres.*
 - (a) Substitutes for cloth prepared by stripping and pounding [e.g. the *Tappa* or *Kapa* cloth of the Pacific Islands].
 - (b) Lace barks [e.g. from *Layetta lintearia* of Jamaica used for frills, ruffles, etc.].
- 2. The *ribbon or layer basts* extracted in thin flexible strips [e.g. Cuba bast used commercially as millinery material; cigarette basts for wrappers].
- 3. *Interlacing structural fibre or sheaths.*
 - (a) From leaves and leaf stems of palms, [e.g. Fibrous sheaths from bases of leaf stalks of the cocoanut].
 - (b) From flower buds. The natural caps or hats from several species of palms.

D. BRUSH FIBRES.

1. *Brushes manufactured from prepared fibre.*
 - (a) For soft brushes [substitutes for animal bristles such as Tampico].
 - (b) For hard brushes [Palmetto fibre, kittiel, etc.].
2. *Brooms and whisks.*
 - (a) Grass-like fibres [e.g. Broom root, broom corn, etc.].
 - (b) Bass fibres; also for coarse brushes [Plassavas, etc.].
3. *Very coarse brushes and brooms.*
Usually twigs and splints.

E. PLAITING AND ROUGH WEAVING FIBRES.

1. *Used in articles for attire as hats, sandals, etc.*
 - (a) Straw plaits. From wheat, rye, barley and rice straws.
 - (b) Plaits from split leaves chiefly palms and allied plants [e.g. Panama hats from finely divided leaves of *Carludovica palmata*].
 - (c) Plaits from various materials used entire and without preparation, [e.g. Basts and thin woods used in millinery trimmings. Chinese sandals from rushes.]
2. *Mats and mattings; also thatch materials.*
 - (a) Commercial mattings from Eastern countries.
 - (b) Sleeping mats made by natives for their own use.
 - (c) Thatching or other covering made of tree basts, palm leaves, grasses, etc.
3. *Basketry.*
 - (a) Manufactures from woody fibre [e.g. osier and splint baskets].
 - (b) From whole or split leaves or stems of endogens. [Chiefly of Indian or native manufacture, from yacca leaves, palm leaves, reeds, grasses, etc.]
4. *Miscellaneous manufactures.*
Willow ware in various forms, chair bottoms from splints or rushes, etc.

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F. VARIOUS FORMS OF FILLING MATERIAL.

1. *Stuffing or upholstery.*

- (a) Wadding, etc., usually commercially prepared lint cotton.
- (b) Feather substitutes. [Kapok, bombax cottons, etc ; tomentum from surfaces of leaves, stems, and leaf bud ; other similar soft material.]
- (c) Mattress and furniture filling. [Tow or waste of prepared fibre ; unprepared bast ; straw and grasses ; substitutes for horsehair ; maize husks, etc.]

2. *Caulking.*

- (a) For seams of vessels, etc. [oakum from various fibres].
- (b) For seams of casks, barrels, etc. [leaves of reeds and giant grasses].

3. *Stiffening.*

In the manufacture of "staff" for building purposes, and as substitutes for cow's hair in plaster. [New Zealand flax ; palmetto fibre.]

4. *Packing.*

- (a) In bulkheads, etc., [e.g. coir, cellulose of corn pith, etc. In machinery, as the valves of steam engines ; various soft fibres.]

G PAPER MATERIAL

1. *Textile papers*

- (a) Spinning fibres in raw state ; waste from spinning mills [tow, jute butts, manila rope, etc.].
- (b) Cotton or flax fibre previously spun, but used as rags for paper material.

2. *Bast papers.*

These include Japanese papers from soft bast, such as the paper mulberry (*Broussonetia*) or species of the genus *Edgeworthia*.

3. *Palm papers.*

From fibrous materials of palms and similar monocotyledonous plants. [Palmetto and *Yucca* papers.]

4. *Bamboo and grass papers.*

Including all paper material from gramineous plants [e.g. bamboos, esparto, maize and the true grasses].

5. *Wood pulp or cellulose.*

Wood of spruce, poplar and similar "paper pulp" woods prepared by various chemical and mechanical processes

Obviously in very many instances the same fibrous material will be found in more than one group, its place in the classification depending mainly upon its principal use or uses.

• **Microscopical Examination of Animal Fibres.**—Any suitably equipped microscope will serve the purpose, low or medium powers being principally required. An efficient sub-stage illuminating combination is especially desirable

The following notes on the methods of examination refer more especially to one of Zeiss's instruments, fitted with Abbe's illuminating apparatus, and an iris diaphragm.

The entire sub-stage can be adjusted nearer or further from the slide, with a view to correct light-focussing, and the iris diaphragm is also capable of a lateral movement, which enables oblique illumination to be employed.

As it is usually found convenient to arrange more fibres for examination than can be accommodated under the customary cover-glass, a useful method is to employ small glass sheets, $3\frac{5}{8}$ inches by 3 inches, on which, in lieu of a cover-glass, the ordinary microscopic glass slide, 3 inches by 1 inch, is used. Besides the advantage of having a greater quantity of fibres available, the weight of the glass slide serves to preserve a flat field.

• For higher powers than, say, $\frac{1}{2}$ inch, ordinary cover-glasses must be used.

The lowest objectives available, such as the "two-inch," are useful, where the curl of fibres has to be compared. For most purposes, however, the two objectives most in use are the AA and C, of Zeiss, modified by such choice of eye-pieces and tube extensions as may be found necessary.

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An important factor to be noted is that the illumination used for the examination of the structure of the scales, cortex or medulla (if present) should be entirely modified when it is desired to observe the disposal of the colouring matter in the cortex. In the first case the light is suitably restricted by means of the iris diaphragm, while in the latter case the diaphragm is thrown completely open, and as much light as possible from some uniform source is directed through the fibres. When this is done, all appearance of scales, medulla, etc., disappear, the faintest profile of the fibres only being visible, but the pigment disposal, in the peculiar characteristic manner of lines and irregular congeries of dots, etc., stands out as clearly as possible.

For this reason no method of artificial illumination is so satisfactory as the light from a sky covered with white clouds, though the more conspicuous forms of fibre colouration can, in default of this, be seen by interposing a sheet of ground or whitened glass between the mirror and the source of artificial light, of which the ordinary mantle used with gas (or better, with a petroleum lamp) is, perhaps, the most suitable.

Where the pigment is nearly obsolete or where comparison has to be made with dyed wool fibres of such faint brownish and yellowish tints as may be employed with a view to resembling naturally coloured wool fibres, artificial light cannot be satisfactorily employed.

If the foregoing precautions are observed, the essential differences between dyed and naturally coloured fibres can be quickly determined, although materials are rarely produced in which the normal shades of most can be so closely imitated as to deceive the naked eye.

Any dyed fibre, unless of so faint a tint as to appear colourless under the microscope, will show a complete uniformity of colouring throughout, from edge to edge; whereas the distribution of the pigments in the cortex of the natural brown fibres occupies definite restricted areas, as mentioned above. The method of such disposal, however, varies very largely in different classes of animal fibres, and often affords a means of distinguishing one kind of fibre from another.

In the case of woollen underclothing, either stockinet or warp and woof material, the fabric is either made of white wool (bleached, to be as white as possible) or else a small percentage of coloured fibres is introduced, producing a pale greyish or brownish appearance, with the result that such a material does not "show the dirt;" nor has it to be subjected to the bleaching process, which latter has sometimes a tendency to increase the liability to shrinkage when such garments are washed.

When a material, such as that used for the natural undyed "Jaeger" garments, is examined it will be seen that the admission of the small proportion of brownish and yellowish fibres into the bulk of the white fibres produces an irregular appearance of small patches of colour, so that to imitate this it would not suffice to employ a uniformly dyed yarn, but specifically dyed fibres, of the colours of sheep's wool, must be introduced in the same fashion. It is here that the microscope can be of infallible service in detecting the dyed fibres by revealing the differences above mentioned, between the pigment disposal of the "natural" fibre, and the uniform, clear, unbroken, transparent colour of the dyed fibre.

It is even possible in some cases where natural brown fibres have been dyed, should the latter not have rendered the fibre too opaque, to see coexistent in the same fibre the lines and areas of pigment showing through the clear and uniform dyed colour.

A precaution may here be noted against classing as "dyed," fibres that from some reason have become "artificially" coloured, such as may have been stained by the sheep's urine or faecal matter, but such fibres rarely are present in large numbers. Their colour is weak and irregular in distribution, their scaly structure usually more or less impaired, so that the analyst can generally without difficulty discount their presence.

Water is the usual medium in which wool fibres can be microscopically examined.

The scaly structure can be well seen by oblique illumination, by throwing the iris diaphragm out of the optical axis of the instrument.

The fibres then have a striking silvery appearance, the projecting edges of the scales catching the light, and the cylindrical nature of the fibres being clearly shown.

Microscopical Examination of Vegetable Fibres.—Much of what has been said above is also applicable to the examination of vegetable fibres, though in many cases the use of higher powers may be required.

For the differentiation of certain fibres, e.g. silk and artificial silk, the microscopical appearance of cross-sections will often be found of use. In making such cross-sections we have found paraffin wax of fairly high melting-point the most suitable medium. A bundle of the fibres is straightened, as far as possible, immersed in the wax at a temperature a little above its melting-point, and the mass then twisted between the finger and thumb until a solid pencil is obtained.

Cross-sections may easily be cut from this by means of a microtome or even with a sharp razor with a little practice.

As a liquid medium in which to examine vegetable fibres under the microscope, ordinary glycerin gives excellent results. In some cases the fibres may be advantageously mounted in Canada balsam.

Stegmata.—The recognition of many fibres under the microscope is facilitated by their containing certain cells derived from the outer portion of the bast of the plant. These cells, known as *stegmata*, may be seen attached, as it were, to the fibre. They contain characteristic amorphous structures, in some cases consisting of calcium oxalate (e.g. in *pandanus* fibres), and in others of siliceous matter. On destruction of the cellulose exterior of the cells by means of chromic acid these siliceous skeletons are left behind as minute shining particles. On ignition of the fibre they may also be observed, in the ash, in some cases forming a connected chain resembling a string of beads.

According to Wiesner¹ *stegmata* are chiefly met with in the fibres derived from monocotyledonous plants, notably the *muscaceæ* and palms. They may be isolated from Manila hemp, cocoa-nut fibre, and the piassavas (q.v.).

¹ "Rohstoffe des Pflanzenreichs," n. p. 201.

Chemical Examination of Vegetable Fibres.—The following scheme of examination devised by Cross, Bevan, and King,¹ forms the basis of most modern chemical methods of judging of the value of vegetable fibres.

Moisture.—The loss in weight at 110° C. gives the amount of hygroscopic moisture. About 1 per cent. of this moisture may be retained at 100° C.

Ash.—This is the residue left on ignition of a weighed quantity. The proportion is relatively low in lignocelluloses; higher in pectocelluloses.

Hydrolysis (a)—This is the loss in weight (calculated upon the dry substance) when 5 grms. of the fibre are boiled for five minutes with a 1 per cent. solution of sodium hydroxide. It indicates the “solvent action” of the alkali.

Hydrolysis (β) represents the loss in weight after boiling the fibre for 1 hour with the alkali solution; and indicates the degree of the “degrading action” of the alkali. The results will give an idea of the degree of resistance that would be offered by the fibre to bleaching processes, and to the action of alkalis such as are used in the laundry.

Cellulose.—This is determined by separation of the non-cellulose constituents by treatment with chlorine and subsequently with sodium sulphite solution as described under JUTE.

Mercerisation.—The loss on weight on treating the fibre with a cold 33 per cent. solution of potassium hydroxide is determined.

Nitration—The fibre is treated with a mixture in equal parts by volume of strong nitric and sulphuric acids and the weight of the product determined.

Acid Purification—A weighed quantity of the substance is boiled for one minute with a 20 per cent. solution of acetic acid, to dissolve impurities, and the residue washed with water and alcohol, dried and weighed.

Elementary Composition.—The percentage of carbon in ordinary cellulose (cotton) is 44.4 per cent. In compound celluloses it may be low (40 to 43 per cent.) in the group containing the

¹ “Report on Indian Fibres, 1886.”

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pectocelluloses, or high (45 to 50 per cent.) in the group containing jute cellulose and other lignocelluloses.

The following results are selected from those given by Cross and Bevan and King to illustrate their method :—

	Mois- ture	Ash	Hydrolysis		Cellu- lose	Mer- curi- sing	Nitra- tion	Acid Purifi- cation	Per cent Carbon					
			α	β										
A	Flax	9.3	9.6	14.6	22.2	81.9	8.4	123.0	4.5	43.0				
	Rhea Boehmeria	9.0	2.9	13.0	24.0	80.3	11.0	125.0	6.5	—				
	Calotropis Q.	7.3	2.5	13.0	17.6	76.5	—	153.0	8.5	44.0				
	Marsdenia T.	4.5	1.5	6.2	10.1	88.3	4.6	131.0	0.8	44.6				
	Sunn hemp	8.5	1.4	8.3	11.7	83.0	11.3	150.5	2.7	44.3				
B	Jute	10.3	1.1	13.3	18.6	76.0	11.0	128.0	2.5	47.0				
	Sida R.	10.7	0.6	6.6	12.2	83.1	6.6	137.2	0.4	45.2				
	Urena L.	10.7	1.8	11.9	18.5	77.7	13.6	—	4.0	—				
	Hubiscus C.	10.6	2.2	14.0	19.5	73.0	16.0	—	—	—				
C	“ E.	10.7	1.5	9.8	14.2	74.0	9.6	—	3.4	45.2				
	Agave A.	10.5	1.4	10.0	20.0	75.8	11.0	109.8	1.1	44.9				
	Sansevieria Z.	9.7	—	12.0	16.5	73.1	—	106.0	2.5	44.5				
	Musa P.	13.4	—	11.0	33.0	64.6	11.0	91.3	4.0	—				
	Furcraea C.	12.2	—	—	11.8	70.0	—	104.0	—	—				

Separation of Ultimate Fibres.—The individual cellulose cells which are united with other substances to make up the staple of the fibre may be isolated by treating the fibre with chromic acid or by Cross and Bevan's method of separating cellulose (p. 152).

The influence of the size of the fibre elements upon the "life" of the fibre when spun into yarn is clearly brought out by Cross and Bevan.¹ They point out that the process of bleaching in the manufacture of the fibre, and the slower oxidation which it undergoes when woven into a fabric and subjected to continual washing, have the same tendency to remove the non-cellulose constituents, and disintegrate the fibre.

Hence jute, the fibre elements of which are only 3 mm. in length, is more readily destroyed by bleaching than flax, which has fibre elements of 40 mm. in length. For in the latter case

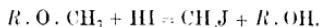
¹ "Indian Fibres," p. 17.

"the superior length enables the mechanical effect of spinning to survive the disintegration of what was the spinning unit".

For a similar reason, cotton offers a greater resistance to the action of bleaching agents than linen. In the case of cotton the ultimate fibre cell is Cross and Bevan's "spinning unit," but in other fibres this unit consists of a bundle of the ultimate cells.

Methyl Value of Vegetable Fibres.—Herzog¹ estimates the amount of lignin in fibres from a determination of the methyl value by the method of Benedikt, Bamberger and Grussmann, the methyl value of pure lignin being taken as 52·9.

This method is based upon the fact that on heating substances containing a methoxyl group with hydriodic acid the methyl group is split off in the form of methyl iodide—



From 0·2 to 0·3 gram of the substance is heated with 10 c.c. of hydriodic acid of specific gravity 1·70 in a flask upon a glycerin bath, a current of carbon dioxide being meanwhile passed through the flask. The vapours produced are conducted through a three-bulb condenser, the first bulb being empty to condense the steam, the second containing water to absorb the hydriodic acid, and the third red phosphorus and water to retain any iodine formed by decomposition of the hydriodic acid. The methyl iodide (and carbon dioxide) issuing from the bulbs pass into a flask containing a mixture of 5 c.c. of a 40 per cent. solution of silver nitrate and 50 c.c. of 95 per cent. alcohol, where the methyl iodide is converted into silver iodide, which is estimated in the usual manner. The "methyl value" represents the weight of methyl ($CH_3 = 15$) equivalent to the silver iodide obtained from 1000 parts of the substance.

In this way the following results were obtained with different fibres:—

¹ "Chem. Zeit.," 1896, xx. 461.

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Fibre	Water Per cent.	Methyl Value on Substance dried at 100° C.	Lignin Per cent.
Bombax cotton, <i>Bombax speciosa</i>	6.77	6.87	12.99
Vegetable silk, <i>Calotropis gigantea</i>	6.88	8.18	15.46
Manila hemp, <i>Musa textilis</i> , hackled	7.81	15.92	30.11
Pite, <i>Agave americana</i>	7.10	8.47	16.02
Aloe, <i>Aloe perfoliata</i>	7.90	9.11	17.32
Coir, <i>Cocos nucifera</i>	7.36	22.00	41.59
Tillandsia, <i>T. usneoides</i>	8.10	11.18	21.13
Nettle, <i>Urtica dioica</i>	8.15	—	—
China grass, ramie	7.84	0.77	1.46
Fibre of <i>Morus papyfera</i>	6.08	2.5	4.74
Linen, Russian	8.40	4.81	0.92
" Courtrai	8.71	—	—
Hemp, Italian, hackled	7.93	2.80	5.33
" Polish, "	8.20	2.87	5.46
Jute	8.06	21.2	40.26

It is thus possible to distinguish chemically between unbleached flax and hemp.

The phloroglucinol test (p. 153) cannot distinguish between the two fibres with much certainty.

Moisture in Fibres.—The amount of moisture in fibres will naturally vary with atmospheric conditions, although Scheurer¹ found that each kind of textile fibre possessed a definite capacity of absorption for moisture when exposed under constant conditions to the action of steam.

Thus when equilibrium had been established the following results were obtained. White cotton, 23.0; raw linen, 27.7; raw jute, 28.4; bleached silk, 36.5; and bleached and mordanted wool, 50.0 per cent. of moisture.

¹ "Bull. Soc. Ind. Mulhouse," 1900, p. 89.

CHAPTER II.

WOOL.

Nature of Wool.—Wool may be defined as a modification of hair characterised by having a scaly surface and a more or less twisted form.

There is no sharp distinction, however, between hair and wool, and both kinds of fibres may frequently be obtained from the same animal.

Thus on the goat there is a lower layer of woolly hair, while the wild Siberian sheep has a hairy coat in summer, which in winter gives place to a covering of wool.

In the case of the domestic sheep long-continued tending under suitable conditions and careful cross-breeding to improve the fleece has made the occurrence of a hairy coating infrequent.

When domestic sheep are allowed to run wild, however, they become more liable to produce hair-like fibres in the fleece.

The quality of the wool is greatly influenced by the effect of external conditions of climate, pasturage, etc., upon the sheep, as well as by the health of the animal.

Commercial Varieties of Wool.—Wool goes by the name of *long wool (tops)* or *short wool (wools)* according to the length of its staple.

The former class includes the long-fibred wools from e.g. Lincoln and Cotswold sheep, and is suitable for manufacture into *worsted yarns*.

The wools of the other class are much shorter, and are used for making *woollen* or *carded yarns*. The short soft fibres of Southdown sheep and merino are representative of these. In addition to these, the wool from certain sheep is known as

middle-wooled, since part of it can be used for worsted and part for woollen yarn.

Kemps is the term given to wool fibres which, owing to imperfect development of the medullary region, have not the absorptive capacity of healthy wool. Hence a fabric containing such fibres has a streaked appearance after being dyed.

The fibres may also be rendered difficult to dye in the process of separation. Thus what is known as *pulled wool* is separated from the skins of slaughtered sheep by being pulled out after a preliminary treatment with lime, which while loosening the fibres also makes them impervious to the dyestuff solution.

Characteristics of Good Wool.—According to Bowman the characteristics of a good wool are: (1) That the length of all the fibres should be as uniform as possible over the largest possible area. (2) That the fibres should have as large a diameter as possible for the kind of fleece, and be uniform and sound. (3) Even distribution and close adherence of scales. (4) Suppleness, elasticity, and uniformity of strength. (5) Good colour and high lustre. (6) Softness to the touch.¹

Merino Wool.—The well-known long-stapled variety of sheep's wool known as merino, was probably indigenous to Spain, and it was not until the 18th century that it was introduced thence into other parts of Europe.

The practice of moving these herds of sheep from one pasture to another at a different season was long regarded as an essential condition for obtaining the finest wool; but it is doubtful to what extent, if any, this has an influence upon the fibres.

The characteristic appearance of merino fibres under the microscope is described below (p. 20).

Microscopical Appearance.—Wool fibres consist of an external layer of imbricating scales, sometimes closely attached to the axis of the fibre, sometimes with their edges projecting so as to show a serrated profile. Within this layer is the cortex of the fibre, which frequently shows longitudinal lines; and

¹ "Structure of the Wool Fibre," p. 178.

within this again, as a central layer, in the coarser sort of hairs and fibres, is the medulla, consisting of granular cells and particles; this area may be continuous, or may show interrupted developments, but can always be clearly discriminated from the two previous layers, if present.

The character of the scaling is an important factor in the discrimination of different kinds of sheep's wool, the integrity of the scales also showing the condition and quality of the fibre.

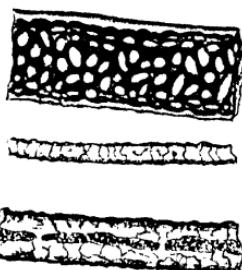
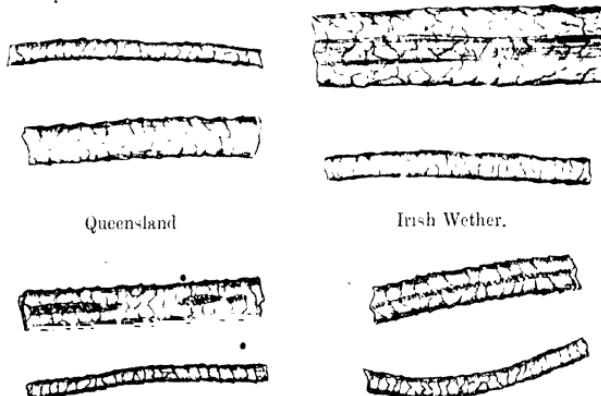


FIG. 1.—Structure of Wool Fibre.
Scotch Black-faced Sheep.



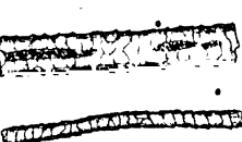
North Hog.

Lincoln Wether.



Queensland

Irish Wether.



New Zealand. Cross-bred

Argentine Cross-bred.

FIG. 2.—Wool fibres from different breeds of sheep.

The scales of merino; for example, will be found to embrace the entire fibre, individually, suggesting a Malacca cane, with

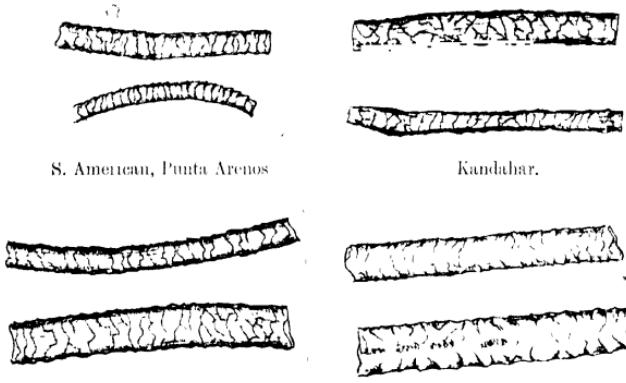


Fig. 3.—Wool fibres from different breeds of sheep.

very close-set joints; whereas in the cross-bred wools the scales are smaller, though clearly marked, and do not individually embrace more than a small section of the fibre-axis.

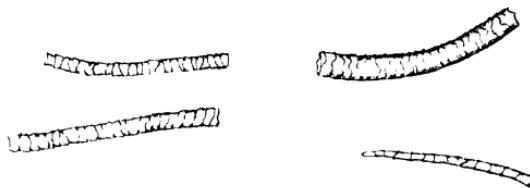


Fig. 4.—Cape Merino Fibres

Fig. 5.—"Finest" Australian Wool.
Showing Scales on Apex of Fibre.

The finer wool fibres show no signs of any medullary area, and the edges of the scales are smooth and straight.

Equally variable is the proportion of the scale that projects from the surface. In some instances, almost a third of the scale may be free. This is an advantage where the wool is to be used for felted material.

In some of the very coarse varieties of wool, again, the edges of the scales appear to fit closely together, the scales themselves assuming a concave instead of the usual convex form.

In wool from lambs that have not yet been shorn fibres from the points of which the scales have been worn away by friction are not of uncommon occurrence.

In cases of disease the scales may also be seen to have been removed from the wool fibre, leaving the exposed cortex in bare patches. Fibres thus affected are obviously much weaker than healthy fibres.

Hanausek gives the following table of the number of scales on a length of 1 mm. of different hair fibres :-

Sheeps' wool (ordinary)	97	White alpaca	90
," merino	114	Brown ,	150
," Saxony	121	Vicuna	100
Angora wool	53	Camel hair	90

The cortex beneath the scales shows longitudinal striations, which may be rendered more pronounced by treating the fibre with caustic alkali and examining it in Canada balsam.

It is made up of cells ranging from 0.0014 to 0.0025 inch in length by 0.0005 to 0.00066 inch in diameter (Matthews).

Mould in Wool.—A speckled appearance occasionally to be observed in dyed wool has been shown by Kalmann¹ to be the result of bacterial action. Its development may be induced by leaving a portion of sound wool in contact with decaying wood in a damp atmosphere at 40° C. The growth of the mould is promoted by dyeing infected wool in an alkaline indigo bath, but is checked by mineral or organic acids. The micro-organism destroys both the fibre and the dyestuff. Mouldy wool dyed with mordant dyestuffs does not show the speckled appearance until dry.

¹ "Farber Zeit," 1902, 13, p. 245.

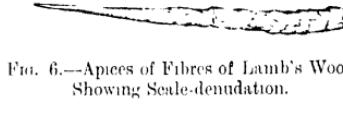


FIG. 6.—Apices of Fibres of Lamb's Wool. Showing Scale-denudation.

Dimensions.—Wool varies considerably in length and in diameter, whether obtained from the same or from different animals.

According to Matthews the average length ranges from 1 to 8 inches and the average diameter from 0·0018 to 0·004 inch.

Tenacity.—The strength of ordinary sheep's wool is only about half that of cotton.

Bowman¹ gives the following figures showing the results of determinations of the relative strengths of different kinds of fibres and of different kinds of wool:—

Human hair, 100; Leicester wool, 119·9; Lincoln wool, 96·4; mohair, 136·2; alpaca, 358·5; and Egyptian cotton, 201·8.

In the similar determinations upon wool, that from a Southdown sheep was selected as the standard: Southdown, 100; Lincoln, 68; Leicester, 72; Cotswold, 64; Australian merino, 85; Shropshire, 78; Oxford, 82; and Cheviot, 75.

Felting Property.—This depends largely on the structure of the fibre, the coarse wools with projecting scales felting much more readily than those approximating to a smooth cylindrical hair-like structure. Treatment with certain substances, such as dilute acids or alkalies, or even boiling with water, acts upon the surface in such a way as to increase the power of the fibres to felt together. It is possible that the scales thus become loosened and rendered more capable of interlocking with one another.

The "Curl" of Wool.—The characteristic wavy structure of wools, which is most pronounced in the fine-stapled varieties, is usually attributed to unevenness of the cortical cells, which causes contraction of the fibres. Wools that approach hair (e.g. mohair) in their structure show little or no tendency to "curl". It has frequently been noted that there appears to be some relationship between the diameter of the fibre, and the amount of waviness. This is shown, for example, in the following table given by Bowman² :—

¹ "Structure of the Wool Fibre," pp. 220, 221.

² *Loc. cit.*, p. 225.

Wool.	Waves per inch.	Diameter inches.
Australian merino	24-30	0.00064
Southdown	13-18	0.00078
Irish	7-11	0.00120
Lincoln	3-5	0.00154
Northumberland	2-4	0.00172

CHEMICAL COMPOSITION.

As taken from the sheep wool consists of the fibre mixed with grease and dried sweat (suint) from the skin, and with various foreign bodies collected from the soil and plants with which fleece has come in contact.

Thus a specimen of merino wool examined after being dried at 100° C. by Chevreul was found to consist of the following substances: Wool fibre, 31.23, suint (soluble in cold water), 32.74; fat (soluble in ether), 8.57; mineral matter, 26.06, and adherent earthy matter, 1.40 per cent.

Elementary Composition.—The true wool fibre, after removal of the wool fat, suint, etc., by scouring with soap and water, is made up of carbon, hydrogen, oxygen, nitrogen and sulphur, the relative proportions of which show considerable variations in the wool from different kinds of sheep.

Thus the following figures were obtained by Bowman¹ in the elementary analysis of different varieties of purified wool:—

Wool	Carbon	Hydrogen	Nitrogen	Oxygen	Sulphur	Loss
	Per cent.					
Lincoln	52.0	6.9	18.1	20.3	2.5	0.2
Irish	49.8	7.2	19.1	19.9	3.0	1.0
Northumberland	50.8	7.2	18.5	21.2	2.3	—
Southdown	51.3	6.9	17.8	20.2	3.8	—

The Sulphur in Wool.—Wool usually contains from about 2 to 4 per cent. of sulphur, and several tests for distinguishing between wool and silk (which is practically free from sulphur) have been based on this characteristic.

¹ *Loc. cit.*, p. 244.

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The larger amount of this sulphur may be extracted from the fibre by treatment with concentrated solutions of caustic alkali, but about 15 per cent. still remains, apparently in the form of a more stable combination.

A further proof that part of the sulphur is present in more than one form is afforded by the fact that on adding acid to a caustic alkali solution of wool the amount of hydrogen sulphide liberated does not account for the whole of the sulphur.

The presence of sulphur in the wool is shown by the blackening that occurs on treating the fibre with a solution of sodium plumbate (prepared by treating a solution of lead acetate with sodium hydroxide until the precipitate first formed is redissolved)

The Protein of Wool.—The protein substances in hair and wool are termed *keratin*, though it is probable that numerous individual substances have been grouped together under the same name.

Mills,¹ from a comparison of various analyses, concluded that keratin had the formula $C_{12}H_{15}N_5SO_3$.

Abderhalden² examined the products of the hydrolytic decomposition of the keratin of horse hair and of goose feathers. The former yielded the following amino acids: Glycine, 4·7; alanine, 1·5; amino-valeric acid, 0·9; leucine, 7·1; pyroldidine-2-carboxylic acid, 3·4; aspartic acid, 0·3; glutamic acid, 3·7; tyrosine, 3·2, and serine, 0·6 per cent.

Lanuginic acid—On dissolving purified wool in a solution of barium hydroxide, removing the barium by means of carbon dioxide, and adding lead acetate the lead salt of an amino acid termed lanuginic acid is precipitated. After separation of the lead by hydrogen sulphide and evaporation of the filtrate the acid is left as a yellowish mass, which yields coloured lakes with dyestuffs.

Knecht found it to have the following composition: Carbon, 41·61; hydrogen, 7·31; nitrogen, 10·26, sulphur, 3·35; and oxygen, 31·44 per cent.

Lanuginic acid is soluble in water and slightly soluble in

¹ "J. Chem. Soc.," 1883, p. 142.

² "Zeit. Physiol. Chem.," 46, p. 31.

alcohol, but insoluble in ether. It forms a plastic mass when heated above 100° C.

Knecht advocates the use of a solution of wool in barium hydroxide solution to "animalize" vegetable fabrics, so as to increase their dyeing capacity.

Mineral Matter.—A large proportion of the mineral matter in wool (apart from adherent earthy matter) is derived from the wool-grease and the suint, the latter containing a considerable amount of potassium salts of fatty acids.

The following analyses of the ash of a sample of Lincoln wool is given by Bowman:¹ Potassium oxide, 31.1; sodium oxide, 8.5; calcium oxide, 16.9; aluminium and iron oxides, 12.3; silica, 5.8; sulphuric acid, 20.5; and carbon dioxide, 4.2 per cent.; together with traces of phosphoric acid and chlorine.

The wool used for this analysis was first scoured with soap and water, and dried. It yielded 1 per cent. of ash, of which 25 per cent. was insoluble in water.

The Pigment in Wool.—Sheep's wool containing a black or brown pigment is relatively uncommon, whereas in the case of camels' hair and some other fibres a pigment is usually present.

The pigment of wool is only slightly affected by dilute acids and alkalies, but is bleached on exposure to light. It can be distinguished from artificial dyestuffs by its mode of distribution within the fibre (see p. 31).

According to Bowman² the pigment in sheep's wool has the following elementary composition—Carbon, 55.40, hydrogen, 4.25, nitrogen, 8.50; and oxygen, 31.85 per cent.

ACTION OF CHEMICAL AGENTS.

Mineral Acids.—Wool is disintegrated by strong mineral acids. Treatment with warm dilute sulphuric acid, however, tends to increase the affinity of the wool for acid dyestuffs.

Organic Acids.—Tartaric and citric acids have a contracting effect upon



FIG. 7.—Wool after Action of Dilute Nitric Acid.

¹ *Loc. cit.*, p. 261.

² *Loc. cit.*, p. 267.

wool when the fibre is subsequently steamed. The wool absorbs these acids to a considerable extent. Other organic acids, such as lactic and oxalic acid, are also absorbed. Unlike silk, wool has but little affinity for tannin.

Thiocyanates.—According to Siefert,¹ contraction of wool without injury to the fibre is effected by treating it with a solution of a thiocyanate and then steaming it. A crêpon effect may thus be obtained. Wool thus treated has an increased affinity for acid dyestuffs but a reduced affinity for basic dyestuffs. The same result may be obtained, though to a less extent, by treating the wool for several days with the thiocyanate solution without subsequent steaming.

Action of Nitrous Acid.—Wool treated with nitrous acid or an acidified solution of a nitrite turns yellow, the colour changing to brown on treatment with boiling water. The diazotised fibre has an increased affinity for dyestuffs, and gives pronounced colorations (orange, red, etc.), when treated with phenols in the presence of an alkali.

Richard² gives the following list of reactions of diazotised wool: Resorcinol, orange, becoming pale red on treatment with sulphuric acid; o-cresol, orange (pale red with sulphuric acid); pyrogallol, yellow-brown (orange with sulphuric acid); α -naphthol, red (black with sulphuric acid); β -naphthol, red (pale red with sulphuric acid).

Flick³ has shown that the yellow compound formed on treating wool with nitrous acid has an increased affinity for basic dyestuffs.

Mercerised Wool.—Although wool is rapidly disintegrated by weak solutions of caustic soda (5° to 70° Tw.), stronger solutions increase the strength of the fibre and render it lustrous.

Buntrock⁴ found that soda solution of 30° Tw. had the greatest solvent action upon wool, while one of 80° Tw. was

¹ "Bull. Soc. Ind. Mulhouse," 1899, p. 86.

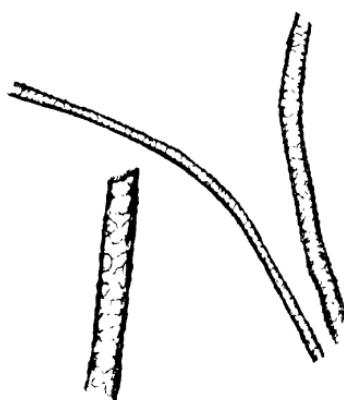
² "J. S. C. I.," 1888, p. 841.

³ "Bull. Soc. Ind. Mulhouse," 1899, p. 221.

⁴ "Farber Zeit," 1898, 9, p. 169.

the best strength for improving the tenacity. An addition of glycerin rendered the sodium hydroxide more effective.

A



B



FIG. 8.—A. Wool Fibres. B. The same Fibres after Treatment with Thiocyanate and Steam.

Matthews¹ confirmed these observations, and studied the

¹ "J. Soc. Chem. Ind.," 1902, 21, p. 685.

most favourable conditions for the mercerising process. Treatment of the wool with caustic soda solution of 80° Tw. for five to ten minutes at a temperature of 18° C. gave the best results. Under these conditions the strength of the fibre was improved, and the surface became lustrous. A final treatment with dilute sulphuric acid followed by thorough rinsing was found the best means of removing the excess of alkali.

The sodium hydroxide solution becomes yellow in the process and contains sulphur extracted from the wool. Thus Matthews found that a yarn which before treatment contained 3·42 per cent. of sulphur, contained only 0·53 per cent. after mercerisation.

The affinity for dyestuffs is increased by the process, but the felting properties of the wool are not reduced.



FIG. 9.—“Mercerised” Wool

Fig. 9.—“Mercerised” Wool

The fibre is not appreciably altered, and the increase in the strength appears to be caused, as it were, by the fusion of the scaly surface into a uniform continuous layer, which is harder than the former surface. This change of physical form would also account for the increased lustre of the fibre and its “scoop” on bending or rubbing.

A similar, though less pronounced, coalition of the scales may be observed in wool treated with weaker solutions of sodium hydroxide.

Chlorinated Wool.—Experiments made by Vignon and Mol-

Examined under the microscope the wool shows a smoother, more transparent surface than before, the scale-marking being very faint. If the fibre is mounted in Canada balsam the medullary region is plainly visible.

In Matthews' opinion the change effected by the alkali is in the main a physical one. The diameter of the

lard¹ show that chlorine as gas or in solution or in bleaching powder modifies the nature of wool and in some cases entirely destroys the fibre.

Bromine has a similar action upon the scales.

Wool thus bleached loses as much as 10 per cent. in weight. Its elasticity and tenacity are, as a rule, considerably reduced; on the other hand the tendency to shrinkage is lessened. Wool that has been treated with chlorine gives brighter colours than ordinary wool with dyestuffs (e.g. methyl violet).

The chlorine does not appear to combine directly with the wool, since free chlorine may be detected in the treated material. The wool also retains its new properties after removal of chlorine by means of sodium bisulphite.

In the reaction the organic matter appears to be affected, free hydrochloric acid and oxidation products being formed.

In carefully-regulated treatment with chlorine, on a manufacturing scale, prominent portions of the wool scales are destroyed, and this appears to have the effect of preventing shrinkage of the wool.

A bath containing mineral salts of weak acids (e.g. aluminium

¹ "Comptes Rend." 1906, 142, p. 1343. "Bull. Soc. Ind. Mulhouse," 1906, 76, p. 254.



FIG. 10.—Fragments of Wool Fibres after Treatment with Bromine Water

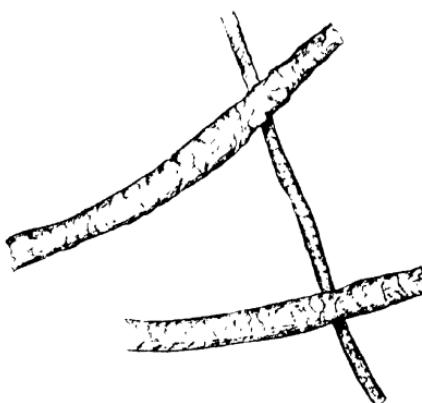


FIG. 11.—Chlorinated Wool Fibres

acetate) is claimed to restore suppleness and softness to the chlorinated wool without destroying its acquired unshrinkability (Eng. Pat. 9044, 1899).

Pearson¹ gives the following details of the method of chlorinating wool for the manufacture of unshrinkable underwear, and tests for distinguishing it: The wool is treated with a solution of alkali hypochlorite prepared from bleaching powder and sodium carbonate. This solution should not contain more than 4·5 per cent. of available chlorine; otherwise chlorate may be formed and cause the wool to turn yellow. After each addition of the hypochlorite solution the liquid is acidified with hydrochloric acid, and the wool is subsequently thoroughly rinsed, and its colour restored by treatment with a bath of sodium bisulphite into which sulphuric acid is gradually introduced. Finally it is thoroughly washed and scoured with soap and a little sodium carbonate.

According to Pearson dry chlorine has no action upon dry wool, and the so-called "moderately chlorinated" wool is devoid of chlorine.

Chlorinated wool has a greater affinity for dyestuffs than ordinary wool, and hence a moderate degree of chlorination is used in the preparation of wool intended to be dyed deep black.

Chlorinated wool may be distinguished from untreated wool by allowing a drop of water to fall upon it. The drop is rapidly absorbed, forming a circular spot, whereas in the case of ordinary wool the drop is very slowly absorbed, and the outline of the wetted portion is irregular.

Apart from the results of comparative dyeing tests chlorinated wool may also be distinguished by its characteristic "scoop" when wetted and rubbed.

Or if fragments of treated and untreated wool be rubbed together an electric charge sufficient to deflect the leaves of an electroroscope is produced.

In Pearson's opinion garments of chlorinated wool do not wear well, and we can confirm this conclusion from our own

¹ "J. Soc. Dyers and Col." 1909, 25, p. 81.

experience in the examination of garments submitted to us by numerous laundries.

Detection of Dyed Fibres.—Wool fibres dyed to resemble those of the “natural” brown, yellowish, or tawny tints are best detected in a yarn or material by microscopic methods; and this is especially the case where both dyed and undyed (coloured) fibres are present in a given fabric.

As brilliant (daylight) illumination should be used as it is possible to obtain, with the iris diaphragm thrown wide open, so that all *external* structure of the fibres disappears.

Under these conditions, the pigment particles in natural-coloured fibres will be clearly seen, in the cortex, in dots or broken lines of disposal, varying much in tint and form, but always, more or less, suggesting an interrupted or stippled colour-surface. In sheep's wool, for example, broken lines of colour are suggested; in camel hair the pigment is seen in isolated blotches or round patches, on a “ground work” of very fine particles, the former like knots in a deal board.

Artificially coloured fibres, on the other hand, exhibit under these conditions, an absolutely uniform colour-surface, unbroken and clear (suggesting coloured liquid in a glass vessel), and may by this means be distinguished from the natural fibres, however nearly the tint may be matched.

In the exceptional case of natural-coloured fibres having also been dyed a darker (or different) tint, both natural and artificial colours can frequently be discerned in the same fibre.

This method of discrimination is specially valuable when examining white woollen goods (such as the “Jaeger” stockings, and their imitations) wherein a small proportion of coloured fibres are incorporated to give a general greyish or yellowish tint to the material.

It must be borne in mind that wool fibres are liable to staining, other than from intentional dyeing, from such agencies as sea-water, urine, etc.

The proportion of such fibres, however, in a given material would never be large, and they can usually be identified microscopically by the pale and irregular dingy colouring. Such fibres

also show, as a rule, structural defects, when examined by reduced light, owing to the action of the urine, etc., upon the scaling.

When exceedingly dark fibres are examined, it may be necessary to cut sections (sliced longitudinally from them) in order to see the pigment plainly; otherwise such fibres (such as stout horse-hair) may prove opaque to the brightest illumination.

The Conditioning of Wool, etc.—Since wool, etc., contains a variable proportion of moisture, the selling price of the material will be largely affected by this factor.

Sales are, therefore, based upon the proportion of moisture in the wool, and the official processes of determining this amount are termed "conditioning".

The method consists in mixing together three samples, weighing from $\frac{1}{2}$ to 1 lb. each, from the bulk to be tested, weighing the mixed sample and drying it at 105 to 110° C. (220° F.) until constant in weight.

The loss gives the proportion of moisture, and the residue gives the amount of dry wool in the sample.

The amount of moisture that would be present in air-dried wool under normal conditions of atmospheric moisture and temperature is then calculated, and added to the weight of the dry substance.

This is termed the "regain," and its proportion is officially fixed in different centres. The permissible regain varies with the kind of the wool. Thus the following standards have been fixed:—

	Regain per Cent
<i>Bradford</i> —	
Wools	16
Tops combed with oil	19
", " without oil	18 $\frac{1}{2}$
Noils	14
Worsted yarns	18 $\frac{1}{2}$
<i>Turin Congress (1875)</i> —	
Tops	18 $\frac{1}{2}$
Yarns	17
<i>Roubaix</i> —	
Wools	14 $\frac{1}{2}$
Tops	18 $\frac{1}{2}$
Woollen yarns	17
U.S.A. (army specification for woollen blankets)	11

Several varieties of apparatus have been devised for the rapid conditioning of wool, etc., under constant conditions. In one of these frequently employed the weighed sample of wool is suspended in a wire basket in an oven, the temperature of which is maintained at 110° C. A hot current of air passes upwards through this oven and escapes from an outlet at the top. The wire holding the basket passes through the floor of a balance case fixed above it, and is attached to one end of the beam. From the other end of the beam is suspended a weight pan which counterpoises the wire basket.

The weight of the air-dried wool is first determined in this balance, and as the moisture is expelled the weights are gradually removed until finally the weight becomes constant.

Equations for calculating various problems connected with the conditioning of wool and other fibres are given by Persoz.¹

For example :—

1. *The legal regain being t (e.g. 17), what percentage of moisture ought the fibre to contain for sale?*

$$x = \frac{100 \cdot t}{100 + t}$$

2. *What is the corresponding regain in a fibre containing x per cent. of moisture?*

$$t = \frac{100 \cdot x}{100 - x}$$

3. *Given the absolute weight, a , of the fibre what amount of water, e , must it absorb to contain x per cent. of moisture?*

$$e = \frac{a \cdot x}{100 - x}$$

According to Persoz² the adoption of 18.25 per cent. as the legal standard in France led to the practice of the wool being moistened before being sold to the spinner. He suggested as a remedy the reversion to the old standard of about 13 per cent. (the average proportion of moisture in wool) and that the weight of the wool fibre with nominal moisture should be found by adding 15 per cent. to the dry weight.

¹ "Conditionnement, etc., de la Soie, etc.," 1878, p. 182.

² "Rev. Gén. des Mat. Col.," 1900, 4, p. 81.

CHAPTER III.

VICUNA, ALPACA, CAMEL HAIR AND OTHER ANIMAL FIBRES.

Vicuna.—Commercial vicuna fibre is obtained from the small South American goat, *Auchenia vicugna* or *vicuña*, which is not a domesticated animal.

The fibres are finer than those of alpaca or camel hair, and are characterised by their very soft, almost greasy, feeling when touched. Very few coarse fibres are found.

When examined under the microscope they appear at the first glance to have no scales, but by careful focussing these may be detected, notably in the slightly serrated edge of the fibre. Most of the fibres are small, and these are all coloured and show no traces of a medulla. In the few fibres of larger size a broad ill-defined medullary region may be made out. A few fibres of moderate size are intermediate to the large and small fibres and show a partially interrupted medulla. In addition to these a very stout, pale fibre is occasionally met with. This is practically devoid of pigment, but contains a black opaque medulla, the granular nature of which may be recognised by the aid of strong transmitted light.

The disposal of the pigment is an important characteristic of vicuna. In the small fibres it is regularly distributed in uniform faintly defined "dashes". These can only be observed by examining the fibre in strongly transmitted light from an Abbe's condenser with a fully-opened diaphragm. This renders visible the pigment, while all structural details of scale and medulla disappear.

In the large medullated fibres, however, the distribution of the pigment may take a different form. In these, in addition

to the streaks and lines found in the smaller fibres, there may occasionally be noticed circular patches of pigment.

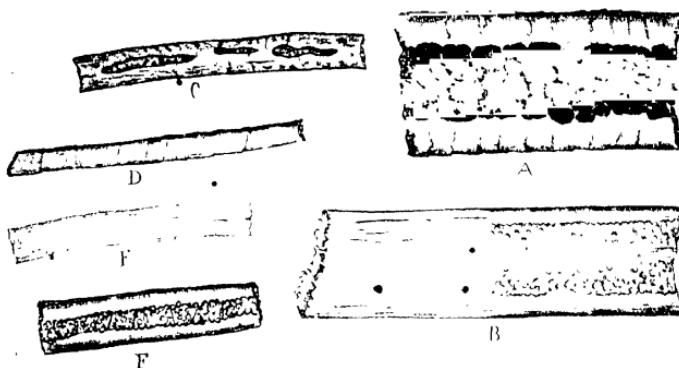


FIG. 12.—Vicuna Fibres.

A. Largest Form, Opaque Black-medulla, Scales faintly indicated, Pigment absent.
 B. Stout Fibre, showing Pigment disposal only, on left side. Medulla Broad, Granules ill-defined, Brown, no Scales seen. C. Smaller Fibre, intermittent Medulla Scales faintly indicated. D. Small Fibre (commonest size) scales unusually well indicated. E. Small Fibre showing Pigment disposal only. F. Fibre between B and C Types, Scales well indicated. All $\times 290$.

The fine woolly hairs usually have a diameter of 10 to 20 μ , while the coarser fibres may reach as much as 75 μ .

Camel Hair.—The hair of the camel is generally used in its natural condition owing to the difficulty of bleaching the pigment.

The fibres are, as a rule, much coarser than those of vicuna, a greater proportion of the larger medullated fibres being present. The scales in the finer more woolly fibres are more conspicuous than in those of vicuna, and to this the softer touch of the latter must be attributed.

The medullated fibres in camel-hair vary very greatly both as regards breadth and continuity of the medulla.

A very stout pale type of hair with black opaque medulla, is occasionally to be observed, as in the case of vicuna.

The distribution of the pigment is very irregular. Some of the finest fibres appear to have none. In other fine fibres flecks

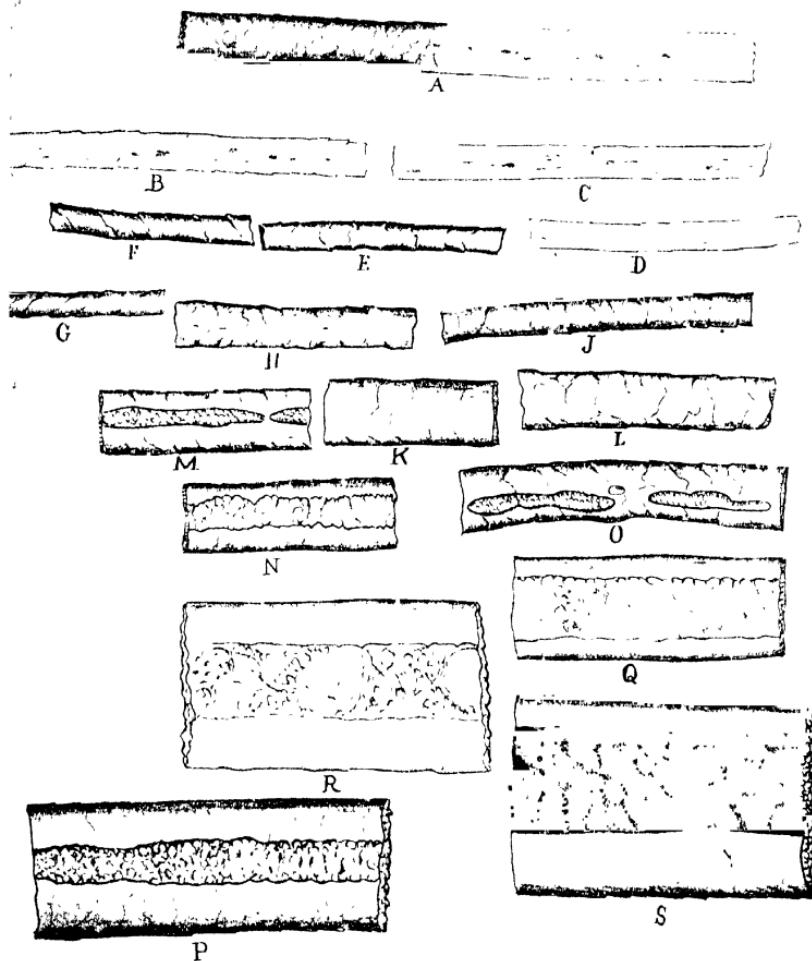


FIG. 13.—Camel Hair Fibres.

A, B, C, D. Non-medullated Fibres, showing Pigment disposal. E, F, G, H, J, K, L. Different Forms of Non-medullated Fibres. M, N, O, P. Different Forms of Medullated Fibres. Q. Medullated Fibre showing Pigment nuclei. R. Fibre showing irregular disposal of Medullary Granules. S. large pale form of Fibre, Pigment finely present, no nuclei; Medulla Black and Opaque. All $\times 290$.

and dashes of pigment may be seen in the otherwise clear transparent hairs. As a rule the edges of the fibre are conspicuously free from pigment. Even in the finest fibres the pigment may here and there be found in the form of circular spots. Generally these are large and conspicuous in the large medullated fibres, but in some fibres this feature is lacking.

The medullary area is better defined than that in vicuna. In comparison with the latter it is frequently very narrow, and the granular masses of which it is composed are coarse and irregularly distributed. The fine woolly hairs usually range from 5 to 6 cm. in length and from 14 to 18 μ in diameter while the coarser hairs are about twice as long and about 75 μ in diameter.

Alpaca is obtained from the S. American goat, *Auchenia paco*. The colour ranges from white to deep brown or black, the red-brown fibres being the most esteemed.

The fibres are coarser than either those of vicuna or camel hair, the stout medullated fibres being present in much larger proportion than the fine woolly fibres. There is also less variation between the diameters of the largest and smallest fibres. Thus the red woolly fibres are about 12 to 35 μ , and the white beard hairs about 35 to 55 μ in diameter. The amount of pigment shows wide variations. Some fibres are quite colourless, while others are of a dark almost opaque brown.

Its distribution is remarkably uniform, and the "knot"-like nuclei, which may be frequently observed in vicuna and camel-hair fibres are completely lacking in alpaca. In some of the palest fibres the pigment is only present in almost imperceptible "dashes".

It would be difficult to distinguish the non-medullated fibres of alpaca from those of vicuna by the distribution of the pigment. The scales are less pronounced than those of camel-hair. The medulla varies very greatly both as regards breadth and coarseness of granulation. In some of the smaller hairs its course is very ill-defined.

Llama hair, derived from *Auchenia llama*, also shows the two classes of fibres to be observed in alpaca fibre, the woolly hairs being about 20 to 35 μ in diameter and the coarser hairs about

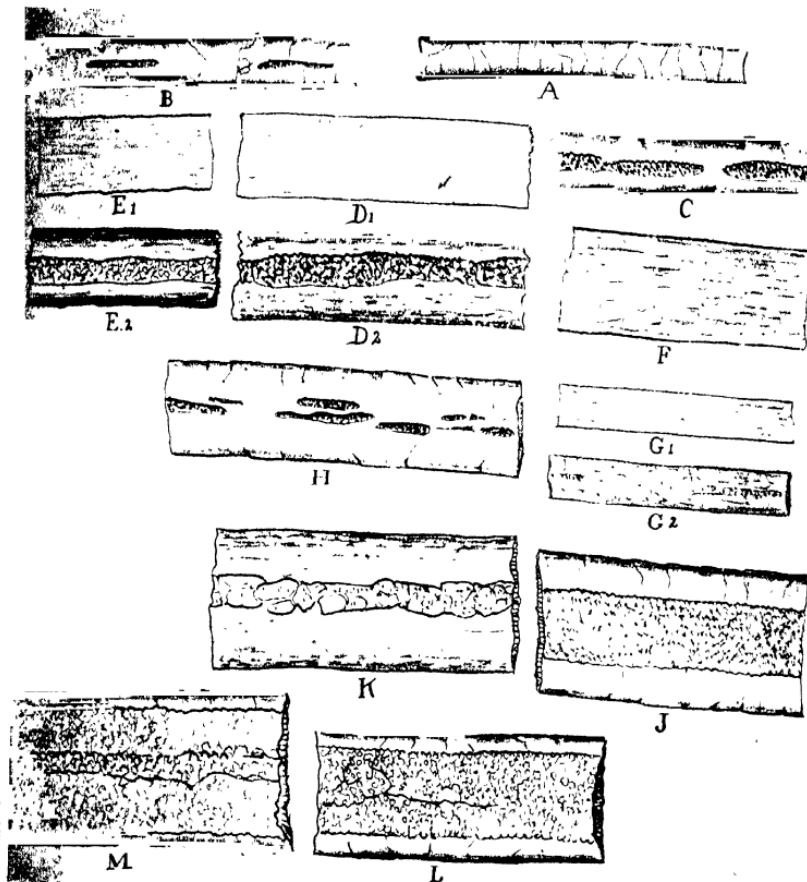


FIG. 14.—Alpaca Fibres.

A. Fibre of the Fine White Class, Scales unusually well indicated. B. Small, Pale Fibre, with early trace of Medulla; well-scaled. C. Same, with Medulla more advanced. D 1, D 2. Identical Fibres, showing (1) disposal of Pigments, and (2) Showing entire Structure. E 1, E 2. Identical Fibres, showing similar features. F. Very Dark Fibre, showing Pigment Disposal only. G 1, G 2. Identical Fibres, showing (1) Vicuna-like Pigment disposed, and (2) Ill-defined Medulla. H, K, J, L, M. Different Varieties of Stout Medullated Fibres. All $\times 290$.

150 μ . Longitudinal markings ("dashes") may be seen on both sorts of fibre, but scales are not readily discernible.

Another species of animal, *Auchenia huanaco*, also yields a fibre, which like llama hair, is usually mixed with alpaca and sold under that name.

Summary of Differences between Vicuna, Camel Hair and Alpaca.—The following table summarises the observations made by one of us (Prideaux)¹ of the characteristic points of difference between these fibres:—

Vicuna	Camel Hair	Alpaca
The finest fibres of the three; few stout medullated examples; scales least conspicuous.	Intermediate in fineness; medullated fibres common; scales most conspicuous.	The coarsest fibres; few non-medullated.
Largest difference in size between non- and medullated fibres.		Least difference between non- and medullated fibres.
<i>Pigment</i> always present, except in a few of the large opaque medullated fibres.	Many of the smaller fibres colourless.	Many fibres, especially larger ones, colourless.
<i>Amount of pigment</i> very uniform; <i>disposal</i> pretty regular; circular nuclei rare, and only in medullated fibres.	<i>Amount of pigment</i> variable; <i>disposal</i> highly irregular; circular nuclei frequently seen in fibres of all sizes. <i>Distinctive streaks and blurs</i> well marked	<i>Amount of pigment</i> very variable; <i>disposal</i> very regularly diffused, in pale specimens almost as if dyed; circular nuclei never seen

Mohair or Angora.—The fibre of the Angora goat, known commercially as *mohair*, is a long, soft, silky hair, reaching up to 8 inches or more in length.

The animal takes its name from the town Angora in Turkey, from which country it has been introduced into South Africa and the United States.

It is largely used in the manufacture of plushes, while the coarser hair is made into carpets and blankets.

¹ "J. Soc. Chem. Ind.," 1900, 19, p. 8.

The diameter averages 40 to 50 μ .

Examined under the microscope the fibres are seen to taper very gradually from the base to the apex, which therefore tends to have a blunt rather than a pointed end.

Most of the fibres do not show the presence of a medulla, but some have a broad medulla similar to that of ordinary goat's hair.

Mohair fibre shows longitudinal striations, which are much more pronounced than are to be found in sheep's wool. It resembles ordinary wool in its curly form.



Fig. 15.—Mohair Fibres.

A. Turkish. 1, End of Fibre with Frayed Apex; 2, Fibre with Discontinuous Medulla. B. C African Mohair. 1, Medullated; 2, Non-medullated Fibre. C. 1 and 2, Mohair from Angora Kid (Cape).

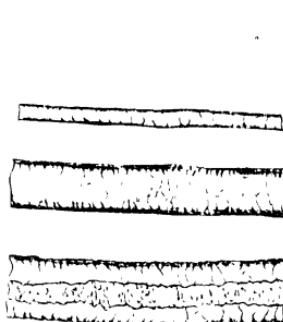


Fig. 16.—Cashmere.

The scaling in the finer fibres is more regular, and the scales themselves are smaller than those of the coarser fibres. The edges of the scales are more pronounced than those of alpaca, although the scaling is more scanty.

Cashmere.—The long, soft, silky wool of the Cashmere goat which is also known as *Tibet Wool*, is used for very fine woollen textiles, and notably the well-known Indian cashmere shawls.

The hair consists of fine, soft, woolly fibres and of coarse beard hairs. The former range from about 1 to 4 inches in length and from 13 to 20 μ in diameter; while the latter are about 4 inches in length and about 70 μ in diameter.

The hair fibres have a well-marked continuous medulla, which is not to be observed in the softer woolly fibres. The contour of the fibre is cylindrical with serrated edge, and the epidermal scales have also serrated edges.

Goats' Hair.—The hair of the common goat, which is used to a limited extent in the textile industry, consists in the main of beard hairs, differing considerably in size and appearance.

Hanausek¹ gives the following description of a typical hair:

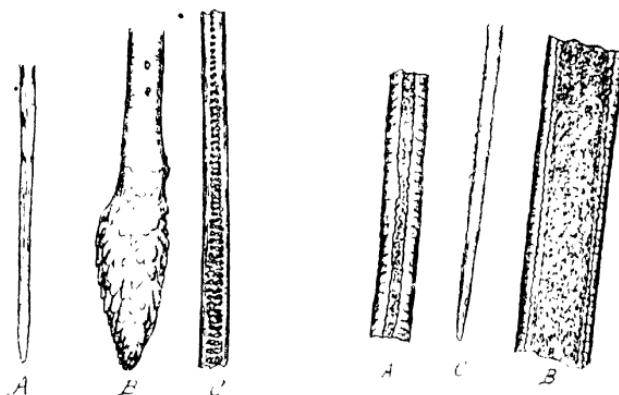


FIG. 17.—Goat's Hair.

A. Apex of Fibre. B. Root of Fibre. C. Medullated Fibre.

FIG. 18.—Cow Hair.

A and B. Medullated Fibres. C. Apex of Fibre.

It is from 80 to 90 μ in thickness at the base and has a root about $\frac{1}{3}$ mm. in length. The medulla begins shortly above the root, and rapidly increases in size until it reaches a diameter of 50 μ at a point where the fibre is 80 to 90 μ thick. The medullary cells are thick-walled and narrow. Towards the middle the hair becomes narrow, but expands again to attain its maximum breadth (about 130 μ towards the point). The medulla contracts as it nears the apex of the fibre. Towards the end the hair becomes very brittle.

Cow Hair.—Since cow hair is not taken from the living animal, but is removed from the skin by liming and pulling in the

¹ "Technische Mikroskopie," p. 124.

process of tanning, it has the drawbacks associated with *pulled wool* (q.v.).

The commercial fibre, which is mainly of Siberian origin, is occasionally used in admixture with wool and other hairs in the weaving of textile materials.

The fibres, which may be white, brown, or black in colour, range from about $\frac{1}{2}$ to 2 inches in length, and have a diameter of about 65 to 130 μ .

They include the three kinds of hair: (1) thick beard hairs; (2) fine beard hairs devoid of medulla; and (3) soft woolly hairs also without medulla.

In the fibres in which it occurs the medulla is pronounced and tapers towards the apex.

Cow hair may be distinguished from goats' hair by the num-

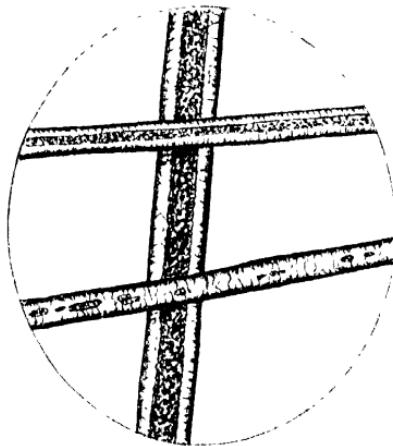


FIG. 19.—Horse Hair.

ber of epidermal scales, by the folds in the medullary canal; and the single rows of cells in the medulla. The medulla does not extend to the apex, which is also usually devoid of epidermis.

Calves' hair has the same structure as cow hair.

Horse Hair.—Most of the horse hair of commerce consists of the stiff bristle-like hairs from the mane and tail of the animal, which are used for upholstery and in small proportion in woven

fabrics to which they impart elasticity.

The body hairs, however, are also used to a limited extent in the textile industries. They are usually under an inch in length and from about 80 to 100 μ in diameter. They are lustrous and of various colours and show a well-marked medullary canal.

Deer Hair.—Hairs of various species of deer that we have examined, including the wapiti, roe, and red deer, are all characterised by an irregular development of the fibre.

Starting from the base, which is moderately narrow and has a prolonged bulb, the fibre suddenly expands and becomes medullated. After continuing as a thick hair for some space it tapers very gradually to the point, preserving its medulla almost to the apex.

The scaling is not very conspicuous, and the edges of the scales do not project to any material extent.

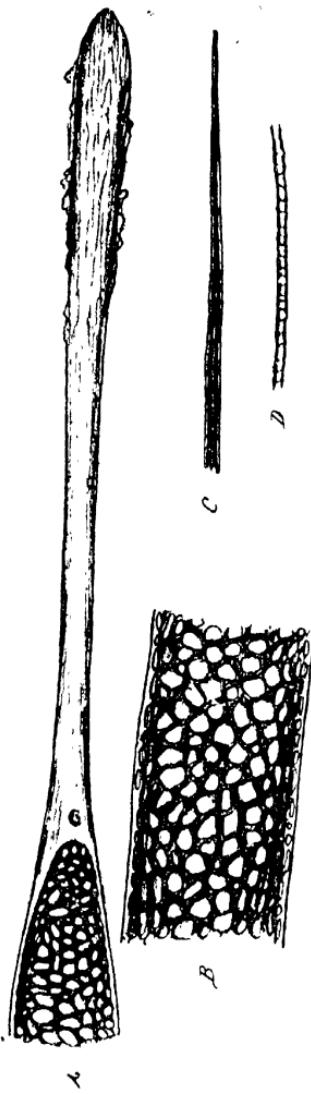


FIG. 20.—Hair from Wapiti Deer.
A. Root of Stout Hair. B. Portion of thickest part of same. C. Apex of same. D. Fibre of Fine Wool

Reindeer Hair.—The fibres of the reindeer range from $1\frac{1}{2}$ to about 4 inches in length. They are hollow flattened hairs, tapering rapidly towards the apex, and still more rapidly towards the base,

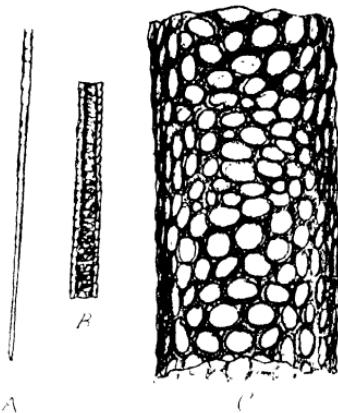


FIG. 21.—Reindeer Hair (from Breast).

A. Apex. B. Same Hair, nearer middle. C. Same Hair at stoutest part.

where the cell-like medulla suddenly ceases. They have a wavy rather than curly outline. The colour is pale brown or white.

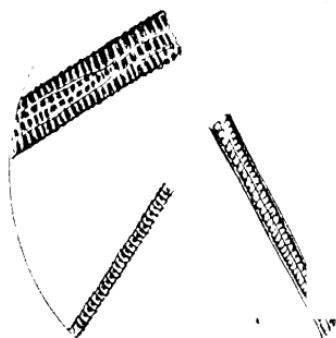


FIG. 22.—Rabbit's Hair.

Rabbits' Hair.—The hair of rabbits, which is chiefly used for

the linings of hats, varies from light to dark brown in colour. It is usually about half an inch in length, and from 30 to 120 μ in diameter. The medullary canal is well-developed, and contains a series of quadrilateral cells arranged in a characteristic fashion, increasing from a single row to 4 and 8 rows in the widest parts of the fibre. The scales are numerous and have sharp points. They are arranged somewhat in the fashion of the jointing of a bamboo cane, each one fitting into the next one.

Cats' Hair.—This is usually from $\frac{1}{2}$ to $\frac{3}{4}$ inch in length, and from 14 to 34 μ in diameter. The apex of the fibre ends in a point. The medulla is well marked and, as is shown in the figure, consists of regularly arranged cells which occupy more than a half of the diameter of the fibre.

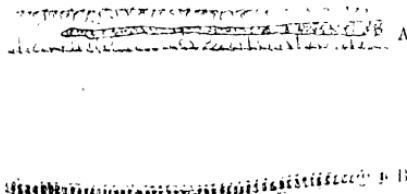


FIG. 23.—A. Portion of Hair of Pekin Spaniel. B. Hair from Persian Kitten.

Dogs' Hair.—Compared with cats' hair the hair of the dog is characterised by its greater diameter, and its relatively narrow medulla, only $\frac{1}{4}$ to $\frac{1}{3}$ the diameter of the fibre. The scaling is well marked, the edges of the scales having a wavy appearance, and giving a serrated edge to the fibre. The fibres vary very greatly in length and diameter. In the figure the hair of a Pekin

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spaniel is shown drawn to the same scale as that of a Persian cat.

Human Hair.—This is fairly uniform in diameter and tapers gradually to a fine point. In the hair of a young child the scales



FIG. 24.—Kangaroo's Hair.
In the Hair of the Kangaroo
the Medulla is very pro-
nounced, and the Serrated
Edge of the Fibre is a very
characteristic feature.

FIG. 25.—Human Hair.
A. Dark-brown Hair from new-born
Female Child. B. Golden Hair from
same Child at age of four. C. Dark-
brown Hair from Adult Female.

are scanty and conspicuous, but in the hair of an adult the scales become very fine, small, numerous, and closely pressed against the axis of the fibre.

Medullated fibres are apparently not formed. In the hair of a young child, the fibres show many resemblances to those of different animals, having, e.g. a jointed appearance recalling that of merino wool.

CHAPTER IV.

SILK.

Origin.—The spinning glands of the mulberry silk worm, *Bombyx mori*, secrete two colourless fluids, which unite on issuing from the glands to form the fibre known as silk. The larger proportion of the fibre consists of what is known as *silk-fibroin*, while the exterior layer of the filaments consists of a sort of gum or silk glue termed *sericin*.

The double thread as present in the cocoon is known as the *bave*, while the single filaments of which it is composed are termed *brins*. Prior to the removal of this silk-glue, which is effected by "boiling off" or *degumming* the fibres in a hot solution of soap, the silk is harsh and relatively lacking in lustre. In the removal of the sericin the fibre loses upwards of 30 per cent. in weight, but becomes soft and lustrous.

The spinning of the cocoon takes about three days, and when complete it weighs about 1·5 to 2·5 grams, about one-sixth or one-seventh of its weight being silk fibre.

Thus, cocoons of the ordinary mulberry silk worm were found to have the following composition: Water, 68·2; silk, 14·3; web and veil, 0·7; and chrysalis, 16·8 per cent.¹

The different varieties of *B. mori* are classified into *univoltine*, which produce only one generation in a year, and *polyvoltine*, which produce several generations. The cocoons of the latter are smaller and coarser than those of the annual varieties.

Reeling.—For reeling the silk the chrysalides in the cocoon are killed by dry heat or live steam (more recently by freezing), the cocoons then immersed in hot water to soften the silk glue, and the silk filaments twisted on a reel to form the threads of

¹ "Silk Worm Culture," Bull. U.S.A. Dep. Agriculture.

raw silk (grège). Only about one-half to two-thirds of the silk in the cocoon can be reeled.

The waste silk from the reeling is mixed with that from the outer part of the cocoons to form *floss silk (échappe)*, which is subsequently made into *spun silk*.

For this purpose it is first treated with a solution of soap and soda to remove the sericin, and then combed and carded. The waste from the spinning is sold as *silk wadding*.

Waste Silk.—The refuse waste silk thus obtained in various stages of silk production is sold under various names, sometimes indicating its origin or the purposes for which it is used. Of the different varieties mention may be made of *watt silk* which is very irregular; *floss silk*, consisting of fibres from the outside of the cocoon; *wadding*, *neri*, etc., consisting of the inner portions of the cocoon; *Cocoons*, or *piques* derived from imperfect cocoons; and *strussa* consisting of silk from double cocoons. The silk from certain varieties of wild silk worms is also only suitable for conversion into waste.

Historical.—References to the silk worm and the manufacture of silk appear in the most ancient Chinese literature. Thus, according to Tshu-King (a French edition of whose book was published in 1770 in Paris) silk culture was an important Chinese industry as far back as 3000 B.C.

From China the use of silk spread into Korea, about the year 200 B.C., its introduction being attributed to political refugees, and it is said to have become known to the Japanese at about the same time.

A race of mulberry silkworms producing a yellow silk appears to have been known from the earliest times in India (Himalayas), but true silk was introduced there by the Chinese. Persia, too, acquired its knowledge of the use of silk from the same source.

Nothing certain is known as to time when silk first became known in Europe, but it was probably introduced prior to the present era by way of India. The fact that silk was used in Rome at an early period is evident from the references made to it by Tacitus¹

¹ "Annals," lib. II, chap. 33

The manufacture of silk invariably followed the course of commerce in raw silk. In the middle ages Arabia was renowned for the beauty of its silk fabrics, and especially for *sammet*, which was a richly embroidered material widely employed for church embroideries and robes of state.

Other mediæval silk fabrics included *baldachine*, a rich material embroidered with gold, made at Damascus; *maramato* (*arramas*) a gold brocade of Arabian origin; *sylatum*, a fabric worked with gold and usually red, in common use for curtains and mantles; and *tiffeta*, of Persian origin, which was in very general use towards the end of the 14th century¹.

The manufacture of silk was well established in the south of France by the middle of the 12th century, having been started by Pope Gregory X. with Italian workmen at Avignon. Two centuries later it was flourishing at Tours and at Lyons, under royal protection, and France was then supplying a large proportion of the silk used in Europe.

Even at that period it was manufactured to a limited extent in England, but so much more was imported from France that in the reign of Mary a law was passed prohibiting the use of silk, except by magistrates and certain other privileged persons. This law was not repealed until the reign of James I.

In 1629 the silk "throwsters" of London became incorporated as a guild, and in 1685 their numbers were enormously increased by the influx of thousands of silkworkers driven out of France by the edict of Nantes.

The majority of these settled in Spitalfields which soon became the centre of the hand loom silk weaving in this country. The growth of the industry in England was still further developed by the introduction of better machinery, and by the reduction of the high duty on raw silk early in the 18th century.

Commercial Varieties of Thread.—Herzfeld² gives the following description of the various kinds of silk threads:—

¹ Michel, "Recherches sur l'commerce des étoffes de Soie, etc.," Paris, 1852.

² "Yarns and Textile Fabrics," p. 89.

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1. *Organzine* (*warp* or *orsey silk*), which consists of 3 to 8 cocoon threads lightly twisted with a right-hand twist to form threads, two or three of which are then twisted together with a left-hand twist.
2. *Tram* or *weft silk*, composed of 3 to 12 cocoon threads united without preliminary twisting to form threads, two or three of which are loosely twisted. This thread is softer and flatter than organzine silk, which on account of its strength is used for the warps in weaving.
3. *Marabout silk* used for crape, consists of 2 or 3 threads united without preliminary twisting, then dyed without scouring and strongly twisted together, so as to yield a stiff thread.
4. "*Soie ondee*," which is prepared by doubling a coarse and a fine thread. It is used in making gauze, to which it gives a watered appearance.
5. *Cordonnet silk* used for braiding, knitting, etc., consists of 4 to 8 threads loosely twisted with a left-hand twist to form the primary threads, 3 of which are then twisted together with a right-hand twist.
6. *Sewing silk* composed of 3 to 24 threads, 2, 4, or 6 of which are united by twisting.
7. *Embroidery silk* composed of untwisted threads, a number of which are united by a slight twisting.
8. *Pol* or *single silk*, used for gold and silver tinsel, is a raw silk thread consisting of 8 to 10 cocoon threads twisted together.

Size of Silk Yarns.—The units of measurement employed to indicate the degree of fineness of silk threads are based upon the weight (*deniers*) of a skein of definite length. The standard of the *denier* varies considerably in different parts of Europe, the following being some of the values in use:—

	Wtight Grams	Length Metres.
Denier (légale) - -	0.05	450
,, (International)	0.05	500
,, (Turin) - -	0.0534	476
,, (Milan) - -	0.051	476
,, (New Lyonese)	0.0531	500

In England and the United States the size is also expressed in terms of the weight in drams of 1000 yards of the silk. This weight may be converted into the corresponding deniers by multiplying it by the factor 33.36.

The threads of the raw silk upon the cocoon have usually a thickness of a little over 2 deniers.

Wild Silks.—The name *wild silk* is applied to the fibres produced by caterpillars, other than *B. mori*. Although some of these wild species are protected against the weather and the attacks of birds, they are not cultivated like the true silk worm.

Silbermann¹ classifies the wild silk worms into the following groups:—

- I. Those with closed cocoons containing fairly uniform silk threads, which can be reeled without much difficulty.
 - (a) Wild mulberry silk worms. (b) *Antherea yama-mai*.
 - (c) Tussah family. (d) Moonga family. (e) *Actias* family.
- II. Those with open cocoons containing silk which cannot be reeled.
 - (a) *Attacus* family.
 - (b) Various other species.
- III. Various species of *Saturnidae*, as yet of no technical value.

Wardle² gives a list numbering three or four hundred species of the different lepidoptera that yield silk.

Among the best known of the numerous commercial wild

¹ *Loc. cit.*, i. 285.

² "Tussur Silk," 1891, p. 40.

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silks are those produced by the caterpillars of the following moths:—

Antherea yama-mai. This caterpillar, found in China and Japan, feeds on the leaves of the oak and produces the commercial *yamamay silk*. This has many characteristics in common with ordinary silk, but is more difficult to dye.

A. pernyi, which produces the tussah silk of China. Like the preceding species it feeds on oak leaves. A cocoon examined by Wardle¹ yielded 492 metres of a fawn-coloured silk.

A. mylitta (India). The caterpillars of this moth feed on the castor-oil plant, and produce very large cocoons containing a coarse gray or brown silk. The *tussah silk* of India is chiefly derived from this source. The name *tussah*, *tussur* or *tussore*, however, is also commonly used as a synonym for all kinds of wild silk.

A. assama (India) is termed the *muga* or *moonga* silk worm from the yellow colour of its cocoon (muga = amber). According to Silbermann (loc. cit.) 1000 cocoons yield about 220 grams of a fawn-coloured silk. A cocoon examined by Wardle (loc. cit.) contained 370 metres of silk.

Actias selene is the most important of this species. It is found in China, Assam and Ceylon, and produces a lustrous gray silk.

Actias luna is a North American species, found chiefly in Mexico, Carolina and Florida.

Attacus cynthia produces a silk which closely resembles tussah silk in its general characteristics. The silk of the Chinese silk worm of this species is also known as *ailanthus* silk, from the name of the plant (*Ailanthus glandulosa*) on which the caterpillar feeds. An Algerian cocoon of this silk worm examined by Wardle yielded 260 metres of a fawn-coloured silk.

A. atlas (China, India), yields the silk known as *fagara* silk, the name being also derived from that of the food-plant of the caterpillar.

A. ricini, another Asiatic species, forms large cocoons yielding a white silk resembling tussah silk in its microscopical and chemical properties. As the name indicates, the caterpillar feeds

¹"J. Soc. Arts," 1855, 33, 675.

on the leaves of the castor-oil plant. According to Wardle (loc. cit.) *erias silk* is derived from this source. A cocoon examined by him contained 320 metres of silk.

Cricula trifenestrata (Assam, Burma) and *Rhoda Newara* (Nepaul) may be mentioned as typical of the silk worms in Silbermann's third class.

The wild silks of Africa are used to a small extent by the natives. The most important are *Bombyx madagascarensis*, the Madagascar silk worm, and *Brocera cajani* which is found in various parts of South Africa.

Microscopical Characteristics.—When examined under the microscope the threads from the cocoon are seen to consist of a double filament coated irregularly with masses of sericin. The breaks and folds in this surface layer have been produced by the bending of the fibroin thread by the caterpillar, and in the unwinding. Silk obtained from cocoons of inferior quality by combing and carding often shows marked irregularities in the deposit of sericin. Threads from the centre of the cocoon have less sericin upon them than those from other parts.

Silk that has been boiled off appears as a shining cylindrical solid rod, fairly uniform throughout its length, and apparently devoid of structure. Only in rare instances does the silk of *Bombyx mori* show indications of longitudinal striations although treatment with dilute chromic acid or moderately strong sulphuric acid causes their appearance.

In von Hohnel's opinion, however, the fibre of true silk has a similar structure to that of the wild silks, and like them consists of fibrillæ, although these are more closely united.



FIG. 26.—Canton Silk (*B. mori*), with
Gum still Attached.

The cross sections of silk, taken from different parts of the cocoon, show notable differences, the filaments from the middle appearing rounder and more regular than the outer fibres. The

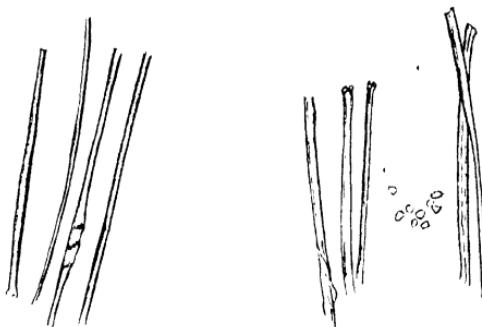


FIG. 27.—Canton Silk from *B. mori* (degummed.)

FIG. 28.—Silk from *B. mori*, Central China (degummed) Showing Cross Section.

innermost portion of the cocoon is a yellow gelatin-like mass consisting of sericin surrounding numerous threads of fibroin. In cross section, the latter appear more oval than the fibres from the middle.

Microscopical Characteristics of Wild Silks.—The silks produced by the various species of wild silk worms differ from true

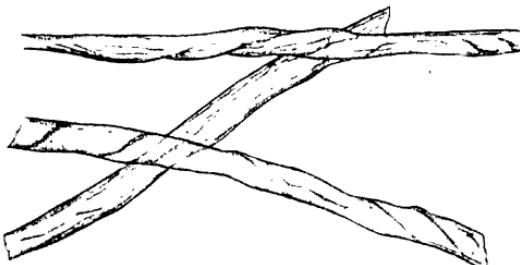


FIG. 29.—Wild Silk from *Antheraea pernyi*.

silk in being much coarser, the diameter of the cocoon threads ranging from about 40 to 60 μ (Hanausek).¹

¹ "Techn. Mikroskopie," p. 139.

Under the microscope the fibroin fibres show numerous longitudinal striations, which von Hohnel attributes to the presence of fibrillæ and air canals, the latter being the cause of the darker markings. These air spaces may be rendered more visible by treating the fibre with chromic acid and sulphuric acid.

Wild silks, and notably tussah silks, occasionally show characteristic broad diagonal markings across the surface. These are due to the impression left by another thread upon the fibre.

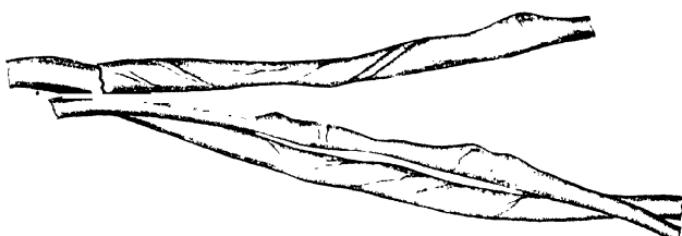


FIG. 30.—Tussore Silk (North China), degummed. Showing Diagonal Markings.

The appearance of tussah silk in polarised light is also very different from that of true silk. Owing to its great variations in breadth the broad side of the fibres shows all the interference colours, whereas the narrow side shows rose or light green flecks on a dark ground (Hanausek).

The table on page 56 embodies von Hohnel's observations on the microscopical appearance of different kinds of silk.¹

Colour.—The colour of natural silk has been shown by Levrat and Conte² to be due to the leaves upon which the silk worms feed, chlorophyll being the parent substance in the case of green silks, and the yellow colouring matter in the mulberry leaves the origin of the yellow colour in yellow silk.

In their experiments leaves were painted with certain artificial dyestuffs, such as toluylene red and methylene blue, and it was found that the silk from caterpillars fed upon these coloured leaves was more or less coloured. The coloration was much

¹ "J. Soc. Chem. Ind." 2, p. 172.

² "Comptes Rend." 1902, 135, p. 700.

more pronounced in the case of the silk of *Attacus orizaba*, than in that of the ordinary silk worm.

Kind of Silk.	Diameter μ	Appearance	
		Broad Side	Narrow Side.
True silk, <i>B. mori</i>	20-25	White or yellowish ; shiny	White or yellowish ; shiny
Senegal silk, <i>B. faidherbi</i>	30-35	Shining yellowish or brownish white or pale yellow, gray, brown and occasionally bluish-white	Gray, brown or black, with occasionally lighter shades
Ailanthus silk, <i>Attacus cynthis</i>	40-50	Shining yellowish white, with yellow brown, or brownish-gray spots	Dirty gray or brown to black, with green, yellow, red, violet or blue spots
Yama-mai silk, <i>Antheraea yamamai</i>	40-50	Bluish-white with dark blue, and black shades	Bright colours, with dark and black shades
Tussah silk, <i>Attacus selene</i>	50-55	Irregular in thickness. Thickest parts with gray and blue spots ; thinner parts white, yellow, or orange-red	Dark gray with pink or light green spots
Tussah silk, <i>Antheraea mylitta</i>	60-65	Similar to <i>A. selene</i> but spots orange-red, red, red or brown	Similar to <i>A. selene</i>

“Seroop” of Silk.—When silk is treated with a dilute solution of acetic or tartaric acid and immediately dried its surface becomes changed in such a way that the material when rubbed or pressed emits a characteristic sound termed its “seroop”.

Wool acquires a similar property when treated with a solution of a caustic alkali, apparently through its surface being hardened in the same way as that of silk by acids.

Lustre.—Silk fibres after removal of the sericin in the “boiling-off” process have a high degree of lustre, due to the physical structure of the surface.

Weighting and dyeing of the silk tend to lessen the lustre,

but the dried fibres may be "brightened" once more by simultaneously steaming and stretching the skeins, or by immersing them in a bath of dilute acetic or tartaric acid and then drying them.

With the object of obtaining a more lustrous dyed silk it is usual to add to a solution of the dyestuff a suitable proportion of the liquid obtained in the boiling-off process, i.e. an impure solution of sericin.

Size of Silk Fibres.—The following measurements made by Haberlandt represent the average diameters of filaments from different parts of the cocoon :—

Species	Outer Layer of Cocoon	Middle Layer.	Interior Layer.
Yellow, Milanese	0.030	0.040	0.025
French	0.025	0.035	0.025
Green, Japanese	0.030	0.040	0.020
White, "	0.020	0.030	0.017
Bivoltine silk worm	0.025	0.035	0.020

Strength and Elasticity.—The figures on page 58 given by Wardle¹ show the variations in size, elasticity and strength of different kinds of silk.

Silbermann² gives the following results in which the observed elasticity is calculated upon a uniform basis of 10 per cent. of moisture :—

Silk (40 to 60 Deniers).	Water	Observed Elasticity.	Elasticity Calculated for 10 per cent. of Moisture
	Per cent.	Per cent.	Per cent.
Japanese	9.3	21.2	21.9
Chinese	12.4	22.5	20.1
Cevennes	8.7	22.2	23.5

¹ "Journ. Soc. Arts," 33, p. 671.

² *Loc. cit.*, p. 182.

Name of Silk.	Country.	Diameter, Inches		Elasticity, Inches in One Foot		Tensile Strength in Drams.		Size of Cocoon, Inches
		Outer Fibres	Inner Fibres	Outer Fibres	Inner Fibres	Outer Fibres	Inner Fibres	
<i>Bombyx mori</i>	China	0.00052	0.00071	1.3	1.9	1.6	2.6	1.1 x 0.5
<i>Bombyx mori</i>	Italy	0.00053	0.00068	1.2	1.9	1.9	2.6	1.2 x 0.6
<i>Bombyx mori</i>	Japan	0.00057	0.00069	1.2	1.4	2.0	3.1	1.1 x 0.6
<i>Bombyx fortunatus</i>	Bengal	0.00045	0.00051	1.8	2.3	1.6	2.8	1.2 x 0.5
<i>Bombyx textor</i>	India	0.00042	0.00047	1.5	1.9	1.4	2.6	1.2 x 1.5
<i>Antheraea mylitta</i>	India	0.00161	0.00172	1.9	2.7	6.6	7.8	1.5 x 0.8
<i>Attacus ricini</i>	India	0.00085	0.00093	1.7	2.0	1.5	3.0	1.5 x 0.8
<i>A. cynta</i>	India	0.00083	0.00097	2.6	2.9	2.4	3.5	1.8 x 0.8
<i>Antheraea assama</i>	India	0.00128	0.00125	2.4	2.9	2.8	4.8	1.8 x 1.0
<i>Attacus selene</i>	India	0.00100	0.00109	2.0	2.8	3.4	4.0	3.0 x 1.2
<i>Attacus atlas</i>	India	0.00102	0.00111	1.9	2.8	2.1	4.1	3.5 x 0.8
<i>Antheraea yamamai</i>	Japan	0.00088	0.00096	2.0	4.0	6.8	7.5	1.5 x 0.8
<i>Cricula trifenestrata</i>	India	—	0.00120	—	—	—	—	2.0 x 0.8
<i>Antheraea pernyi</i>	China	0.00118	0.00138	2.0	2.7	3.2	5.8	1.6 x 0.8

Specific Gravity.—The following figures, quoted by Silbermann¹ from Vignon's determinations, show that the specific gravity of silk varies with the species of silk worm that produced it:—

	Indian Tussah	Chinese Tussah.	Adan- thus,	Erias.	Yama- mai.	Rondotia mentana.	Theophila mandurica	Spinning Silk.
Raw Silk	1.165	1.158	1.157	1.155	1.166	1.152	1.150	1.139
Boiled-off Silk	1.146	1.1405	1.139	1.133	1.143	1.135	1.133	1.118

Silk	Sp. Gr.	Silk.	Sp. Gr.
<i>Cocoon Fibres</i> —			
Italian	1.101	Raw Silks—	
French	1.118	Chinese (Tussah)	1.163
<i>Raw Silks</i> —			
French	1.139	Boiled-off Silks—	
Italian	1.101	French	0.908
Japanese	1.152	Italian (Piedmont)	0.921
Chinese (Canton)	1.163	Japanese	1.023
		Chinese (Canton)	0.985
		Chinese (Tussah)	1.125

Chemical Composition.—The following early analysis of raw silk made by Mulder is quoted in all the text books on silk: Silk substance, 54; substances soluble in water, 28.5; soluble in alcohol, 1.4; soluble in ether, 0.04; and soluble in acetic acid, 16.3 per cent.

From these results this silk was calculated to have the following composition:² Fibroin, 54, gelatin, 20; albumin, 25; wax, 1.1; fat, 0.2; and colour, 0.03 per cent.

Richardson³ found a good specimen of mulberry silk to have the following composition: Water, 12.50; fatty substances, 0.14; resinous substance, 0.56; sericin, 22.58; fibrom, 63.10; and mineral matters, 1.12 per cent.

¹ *Loc. cit.*, ii, pp. 175, 178.

² Silbermann, *loc. cit.*, n. p. 290.

³ "J. Soc. Chem. Ind.", 1893, 12, p. 427.

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A specimen of raw tussah silk examined by Bastow and Appleyard¹ gave the following analytical results:—

	Per cent.
Substances soluble in hot water	21.33
" " alcohol (fatty acids)	0.91
" " ether	0.08
Total loss on boiling with 1 per cent. soap solution	26.49
Mineral matter	5.34

Silbermann² gives the following analyses of two kinds of raw silk. These illustrate the difference in composition between the average threads in the cocoon and those that can be reeled:—

	White Raw Silk.		Yellow Raw Silk	
	Cocoon	Reeled	Cocoon	Reeled
	Per cent.	Per cent.	Per cent.	Per cent.
Fibroin	73.59	76.20	70.08	72.35
Sericin	22.28	22.01	24.29	23.13
Mineral salts in fibroin	0.09	0.09	0.16	0.16
Wax and fat	3.02	1.36	3.46	2.75
Salts	1.06	0.3	1.92	1.60

The difference in elementary composition between the cocoon threads of true silk and tussah silk and their respective fibroins is shown in the following analyses also due to Silbermann³:—

	Mulberry Silk		Tussah Silk	
	Cocoon	Fibroin	Cocoon	Fibroin.
	Threads.		Threads	
Carbon	46.77	47.47	46.96	48.50
Hydrogen	6.21	6.37	6.26	6.34
Nitrogen	17.57	17.86	17.6	18.37
Oxygen	28.25	28.01	26.39	26.39
Ash	1.20	0.29	2.85	0.40

Organic Constituents.—The two organic constituents of

¹ "J. Soc. Dyers and Col.," 1888, 4, p. 89.

² *Loc. cit.*, n. p. 210. ³ *Ibid.*, n. p. 210.

silk, *fibroin* and *sericin*, are protein substances, which may be classified among the amino acids.

Hence silk gives positive reactions with Millon's¹ solution and in the biuret test for proteins. The presence of an amino group is shown by treating the fibre with an acidified solution of sodium nitrite, washing the diazotised product and then adding a solution of phenol, or resorcinol, pronounced colorations being then obtained.

Experiments made by Abderhalden and Dean² have shown that the silk worms prior to spinning contain a large amount of the amino acids, tyrosine, glycocoll, and alanine, which are characteristic constituents of the silk itself. The silk protein, however, may not be present in a ready-formed state in the silk worm, but only produced by metabolic processes brought about by the silk glands.

Fibroin.—The silk fibroin left after removal of the sericin by means of hot soap solution is insoluble in solutions of ammonia and sodium carbonate, but dissolves in solutions of caustic alkali (2 per cent. and over).

The following elementary analyses are quoted by Silbermann:—³

	Staedeler. Per cent.	Gerhard. Per cent.	Cramer. Per cent.	Schutzenberger. Per cent.
Carbon	48.60	48.53	48.39	48.60
Hydrogen	6.40	6.50	6.51	6.30
Nitrogen	18.89	17.35	18.40	18.70
Oxygen	26.11	27.62	26.70	26.25

According to Staedeler the formula of fibroin from ordinary silk is $C_{15}H_{23}N_3O_5$, that from tussah silk being $C_{15}H_{25}N_3O_7$.

¹ Millon's reagent is prepared by dissolving 1 c.c. of mercury in 10 c.c. of nitric acid (sp. gr. 1.14) and diluting the solution with twice its volume of water. Tested with this reagent a solution containing a protein substance gives a white precipitate, which becomes red on boiling.

The biuret reaction is the violet coloration obtained when dilute copper sulphate solution, followed by an excess of sodium hydroxide, is added to a protein solution.

² "Zeit. physiol. Chem.," 1909, 59, p. 170.

³ "Die Seide," n. p. 13.

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Schützenberger's formula is $C_{71}H_{167}N_{24}O_{25}$; while that given by Vignon is $C_{22}H_{47}N_{10}O_{12}$; and that given by Richardson,¹ $C_{69}H_{94}N_{18}O_{25}$.

The fibroin of silk differs from the corresponding protein of wool in containing no sulphur, and on this fact is based methods of distinguishing between the two fibres in mixtures.

On treatment with hydrochloric acid fibroin is hydrolysed with the formation of various mono-amino acids.

A purified specimen of the fibroin from tussah silk examined by Bastow and Appleyard (loc. cit.) had the following elementary composition, excluding 0.226 per cent. of mineral matter: Carbon, 47.18; hydrogen, 6.30; nitrogen, 16.85; and oxygen, 29.67 per cent.

The ash consisted of: Soda, 12.45; potash, 31.68; alumina, 1.46; lime, 13.32; magnesia, 2.56; phosphoric acid, 6.90; carbonic acid, 11.14; silica, 9.79; chlorine, 2.89; and sulphuric acid (SO_3), 8.16 per cent.

Tussah silk fibroin offers much more resistance than the fibroin of ordinary silk to the action of solvents.

There are very great differences in the proportion of fibroin yielded by silks from the same races of *B. mori*, these depending upon the conditions of food, culture, etc. Thus variations in the amounts of fibroin from 73 to 84 per cent. have been recorded,² and it is therefore obviously impossible to base an estimate of the purity of the silk upon the results of this determination.

Moreover since the proportion of substances soluble in a soap solution varies from about 16 to 27 per cent., it is possible to add to their amount by artificial means.

The permissible limits of these impurities were found by estimations made upon a large number of samples of known purity from different districts, of which the following results obtained with ten samples are typical:—

¹ "J. Soc. Chem. Ind." 1893, 12, p. 426.

² "Report of Milan Commission on Silk," 1906.

	Minimum	Maximum	Mean
	Per cent	Per cent	Per cent.
Substances soluble in 3 per cent. soap solution -	21.449	25.913	22.865
In distilled water at 50° to 55° C. -	0.447	1.053	0.617
In ether -	0.104	0.451	0.275
Ash -	0.726	1.903	0.855

The following figures were obtained with various species of silk:—

Species.	Loss on Washing	Boiling Off	Ether Extract	Ash.
	Per cent	Per cent	Per cent	Per cent.
White Kutais -	0.57	22.16	0.55	0.83
White Turkestan -	0.32	21.44	0.31	0.91
Yellow Adrianople -	0.54	24.88	0.35	0.88
Yellow Greek -	0.69	24.64	0.26	0.91
White Chinese crossed with Italian -	0.59	22.48	0.39	0.81

Sericin.—A pure preparation of sericin may be obtained by adding acetic acid to a solution of crude sericin, and extracting the washed precipitate with alcohol and with ether. A pure product thus obtained by Bondi¹ contained 45.0 per cent. of carbon, 6.32 per cent. of hydrogen, and 17.14 per cent. of nitrogen. It was readily soluble in water, but was converted into an almost insoluble modification when heated for three hours with water at 110° C. Sericin loses its power of gelatinisation when heated at 200° C. in a closed tube.

Sericin is soluble in alkali solutions. It can be precipitated from its aqueous solution by the addition of lead acetate.

According to Bolley² purified sericin has a composition corresponding to the formula $C_{15}H_{25}N_5O_8$, while Richardson (*loc. cit.*) assigns to it the formula $C_{16}H_{25}N_5O_8$.

In the opinion of Fischer and Skita³ the difference between

¹ "Chem. Centralbl.," 1902, i, 763.

² Quoted by Silbermann, *loc. cit.*

³ "Zeit. physiol. Chem.," 1902, 35, p. 221.

sericin and fibroin is a quantitative one, for the same products of decomposition are obtained in the hydrolysis of both.

Hydrolysis of Silk Proteins.—In determining whether the proteins of two fibroins from different silks are identical it is assumed that if both yield the same products when submitted to partial and complete hydrolysis they may be regarded as identical in composition and structure.

The following results have thus been obtained :—

Canton Silk is white and has a somewhat finer filament than Italian silk. A sample of the raw silk examined by Abderhalden and Behrend¹ yielded 20·83 per cent. of sericin, while the fibroin contained 5·1 per cent. of moisture (loss at 100° C. per cent.) and 0·32 per cent. of ash.

On hydrolysis the following amounts, calculated on the ash-free fibroin, of mono-amino acids were obtained: Glycocol, 37·5; alanine, 23·5; serine, 1·5; leucine, 1·5; aspartic acid, 0·17; phenylalanine, 1·6; tyrosine, 9·8; proline, 1·0 per cent.; and glutaminic acid, nil. These results closely resemble the corresponding figures obtained by Fisher and Skuta for Italian silk fibroin.

New Chwang Silk is a commercial Chinese variety, the exact origin of which is unknown. A sample examined by Abderhalden and Rilhet² contained 10 per cent. of moisture (loss at 120° C.) and yielded from 18·9 to 20 per cent. of silk glue, while the residual fibroin contained 2 per cent. of ash.

On hydrolysis with acid (to which it offered greater resistance than Milan silk) it yielded the following amino acids (calculated on the ash-free fibroin): Glycocol, 19·7; alanine, 23·8; leucine, 1·6; serine, 1·0; aspartic acid, 2·9; glutaminic acid, 1·7; phenylalanine, 1·2; tyrosine, 9·8; and proline, 1·85 per cent.

In each estimation a correction was made for the proportion of undissolved residue from the hydrolysis.

Moisture.—Silk has a great absorptive capacity for water, and may absorb 25 per cent. or more without becoming unsaleable. In the conditioning of silk the permissible regain has

¹ "Zeit. physiol. Chem.," 1909, 59, p. 236.

² *Ibid.*, 1909, 58, p. 334.

been fixed at 11 per cent., corresponding to a percentage of 9.91 of moisture in the fibre.

After removal of the sericin in the "boiling-off" process silk is much less hygroscopic.

The Milan Commission (1906) adopted a temperature of 140° C. for the conditioning of silk, owing to the difficulty of drying silk at temperatures of 110° to 120° C.

The presence of glycerin or other soluble substances will cause the amount of water to appear too high.

Mineral Matters.—The proportion of ash left on the ignition of genuine silk rarely exceeds 1 per cent.

Action of Chemical Agents on Silk.—Strong acids dissolve silk more or less rapidly, while weak organic acids, such as tartaric or acetic acids, are absorbed, the lustre being thereby improved.

Sulphuric Acid has a strong solvent action upon silk, but when allowed to act for only a limited time effects a marked contraction of the fibre. Tussah silk is affected to a much less extent, and advantage is taken of this fact in the manufacture of silk crape from a mixture of ordinary and tussah silks.

Nitric Acid imparts to silk a yellow coloration which may be bleached by stannous chloride. This colour is rendered darker by solutions of alkalies. Silk that has been treated for one minute at 45° C. with nitric acid of sp. gr. 1.33, yields a gelatinous mass on subsequent treatment with sulphuric acid. The yellow coloration (due to the formation of a xantho-proteic acid) is apparently produced by the nitrous compounds in the acid.

Hydrochloric Acid.—Silk is rapidly dissolved by the concentrated acid, which is therefore employed as a reagent for separating silk from cotton and wool.

In a more dilute form (29° Tw.) the acid causes contraction of the fibre without appreciable injury. A method of craping silk is based upon this property.¹

Hydrofluoric Acid.—A dilute 5 per cent. solution does not attack silk fibres to any great extent and is used for the extraction of weighting substances.

¹ Farrel, "J. Soc. Dyers and Col.", 1905, p. 70.

Zinc Chloride.—Silk is soluble in concentrated solutions of this salt, being reprecipitated on dilution with water. An ammoniacal solution of the precipitate thus obtained has been used in coating vegetable fibres with a layer of silk. A boiling 50 per cent. solution is used as a reagent for separating silk from cotton, the latter losing less than 2 per cent. in weight in the process.

Cupramorium Solution dissolves silk.

Nickel Oxide in Ammonia Solution.—This is used as a reagent for separating silk and cotton, the latter losing only about 1 per cent. by treatment with the hot solution.

Stannous Chloride.—Silk is soluble in a concentrated solution of this salt.

Sodium Chloride has a curious effect in staining and rendering silk tender (see *Weighting of Silk*).

Alkalies. In dilute solution alkalies do not affect silk to the same extent as wool. Hot concentrated solutions rapidly dissolve it.

Ammonia dissolves the sericin, but only attacks the fibroin very slowly.

Absorption of Tannin.—Silk has a much greater affinity than other textile fibres for tannin. Vegetable fibres absorb only a small proportion, and even that may be subsequently readily extracted by cold water. Wool, again, has but little absorptive capacity for tannin in the cold, while hot solutions of tannin render the fibre hard.

Silk will absorb and fix a large amount of tannin from a cold solution, while from a hot solution it will take up as much as 25 per cent. of its weight.

From experiments made by Heermann¹ it appears that an extract of gambier yields a very large proportion of its tannin to silk either in the undyed state or when dyed with Prussian blue, or mordanted with tin chloride.

Dyeing of Silk.—Silk has a great absorptive power for dye-stuffs. It resembles wool in behaving both as an acid and a

¹ "Farber Zeit," 1908, 19, p. 4.

base towards them, probably owing to its constitution being that of an amino-acid.

Three theories are put forward in explanation of the process of dyeing silk, viz. a purely mechanical and purely chemical theory, and Witt's solution theory (1891), which is intermediate to these. This last theory affords an explanation of the extraction of magenta from silk by hot alcohol, and its re-absorption by the fibre on diluting the alcoholic solution with water. Knecht,¹ however, points out that this experiment is also susceptible of a chemical explanation.

Weighting of Silk.--The practice of weighting silk is probably centuries old, for it has long been known that silk possesses a great affinity for tannin, but it is only within the last twenty-five years, that the addition of foreign matter to silk has become almost systematic.

The nitrogenous constituent of silk, *serum*, combines readily with numerous chemical substances to form insoluble compounds. Thus it will enter into combination with a considerable proportion of sugar, and this property has been utilised by the manufacturer in the production of heavy silks of a light colour.

The most general method of weighting silk, however, is by means of treatment with solutions of metallic compounds, and especially compounds of tin. To such an extent had the process gone that a few years ago the manufacturers of Zurich and Crefeld agreed to limit the weighting of silk warp to 20 to 30 per cent., and that of the weft to 60 to 80 per cent. Apparently this self-denying ordinance did not prove altogether successful, for the agreement was not renewed at the International Conference at Turin in 1905.

The effect of weighting with metallic salts is to reduce very greatly the strength of the fibre. Thus Strehlenert² showed that the strength of French silk dyed black and weighted to the extent of 140 per cent. was less than one-sixth of that of pure crude French and Chinese silk.

It has been found by Meister³ that sunlight has a rapid

¹ "Ber.," 1902, 35, p. 1022. ² "Chem. Zeit.," 1901, p. 400.

³ "Bull. Soc. Ind. Mulhouse," 1906, p. 128.

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deteriorating effect upon silk weighted with tin phosphate and silicate, the fibres becoming very brittle on storing. Red spots are often spontaneously formed on such fabrics, the probable origin of which is to be found in the salt contained in the perspiration from the workmen's hands.

Treatment with preparations containing ammonium sulphocyanide, glycerin and tannin diminishes the deterioration by sunlight of silk weighted with tin compounds.

In the *Neuhaus* process, now largely employed, the silk yarn is treated with a solution of stannic chloride (25° to 30° Bé.) and with a solution of sodium phosphate and silicate, and it is claimed that the fibres thus weighted are much less affected by sunlight than silk weighted in the older way with stannic hydroxide.

According to *Silbermann*¹ the destructive action of sunlight is greatly reduced if stannous salts are absent. When such salts are present the strength of the fibre rapidly deteriorates in the light, and more slowly in darkness.

For the detection of the compound formed between the sericin and the stannous salts, the silk is heated with an acidified solution of mercuric chloride. In the presence of tin in the stannous condition mercurous chloride is deposited on the fibre, and forms a dark grey compound on treatment with hydrogen sulphide.

The presence of ferrous salts in the iron mordant used in dyeing silk black shades has a similar destructive action upon the fibre.

The presence of tin in weighted silk is readily detected by burning a little of the material in a basin, mixing the charred residue with potassium cyanide and heating the mixture on charcoal in the blowpipe flame. Minute globules of the metal are formed, and their nature may subsequently be confirmed by the usual tests for tin.

In addition to tin the compounds of uranium, bismuth, lead, tungsten, and antimony are also now employed in the weighting of silk (*Silbermann*).

¹ "Zeit. Farb. u. Textil-Chem.," 1902, i. p. 464.

Action of Salt on Weighted Silk.—Even a very weak solution of common salt has a pronounced deteriorating effect upon silk that has been weighted with metallic compounds. Thus in Sisley's experiments the fibres of weighted yarn, which had been treated with a 0·5 per cent. solution of sodium chloride and then exposed to the air were destroyed in 12 months, whilst a solution of 2 to 5 per cent. strength disintegrated them in a week. The production of stains by the action of salt upon weighted silk has been mentioned above.

Weighting of Dyed Silks.—According to Sisley¹ the best method of determining the amount of weighting in dyed silk is to calculate the proportion of fibroin from the results of an estimation of nitrogen by Kjeldahl's method. It was found that dry "boiled-off" silk contained on the average 18·38 per cent. of nitrogen, corresponding to 16·56 per cent. in material containing the normal proportion of water (10 per cent.).

From 1 to 2 grms. of the silk are boiled for ten minutes with 25 per cent. acetic acid, then rinsed in water, immersed for ten minutes in a 3 per cent. solution of trisodium phosphate at 50° C., again rinsed, and then boiled twice for twenty minutes in a solution of 3 per cent. of soap and 0·2 per cent. of sodium carbonate.

The silk thus purified is wrapped in cotton muslin and gently heated with 20 c.c. of strong sulphuric acid, 10 grms. of potassium sulphate, and 0·5 grm. of copper sulphate until effervescence ceases, after which the liquid is boiled until colourless, and the ammonia distilled in the usual way.

Gnehm and Dürsteler² regard the nitrogen method as most accurate, though in many cases the following rapid extraction methods may take its place:—

Silk Dyed with Colours.—The material is twice extracted for fifteen minutes with hydrofluoric acid (1 to 2 per cent. strength) at 50° to 60° C. In the case of silk weighted with tin silicate and tin phosphate the material may be treated with dilute hydrochloric acid and hydrogen sulphide at 70° to 80° C., for thirty

¹ "Gen. Rev. Mat. Col." 1907, 11, p. 97.

² "Farber Zeit." 1906, 14, pp. 218, 233, 249, 269, 286, 299.

minutes, then for five minutes with a 4 per cent. solution of sodium hydrosulphide at 40° to 50° C., and lastly for fifteen minutes with a 2 per cent. solution of sodium carbonate at 60° to 70° C., the residue consisting of pure silk fibrom.

If aluminium compounds are also present this extraction process must be repeated.

Black Silks.—When the weighting material is tin phosphate alone extraction with 1 to 2 per cent. hydrofluoric acid (or 3 to 5 per cent. oxalic acid solution) followed by a treatment with a 2 per cent. solution of sodium carbonate gives good results.

In the presence of iron it is best to extract the silk with 1 per cent. of hydrochloric acid, then with 4 per cent. sodium hydrosulphide solution, and lastly with 2 per cent. sodium carbonate solution. The results, however, are somewhat low.

The nature of the weighting material is best determined in the ash obtained from the oxalic acid extract.

Scheurer and Silbermann¹ recommend the following method of detecting traces of tin in mordanted fabrics: The material is boiled with 4 per cent hydrochloric acid, and the tin precipitated from the solution by means of pure zinc. It is next redissolved in acid, and the solution made alkaline with sodium hydroxide, and tested with a solution of 5 parts of bismuth nitrate in 500 parts of dilute nitric acid (1:4). In the presence of traces of tin a brown coloration is obtained.

Persoz² has described a similar method of extraction for black silks, the silk fibrom finally obtained being dried and weighed. The amount of weighting is then calculated by means of the formula:—

$$(100 - n) \frac{a}{b} - 100,$$

where *a* represents the amount of weighted silk taken, *b* the pure silk obtained, and *n*, the percentage decrease in the weight of the original (unweighted) silk when boiled off.

In the case of coloured silks the amount of weighting may

¹ "Bull. Soc. Ind. Mulhouse," 1906, **76**, p. 357.

² "Rev. Gen. Mat. Coll.," 1906, **10**, p. 321.

be calculated from the weight of ash obtained from the silk after extraction with hydrofluoric acid.

Scheurer and Silbermann¹ recommend the following method of detecting tin in mordanted fabrics: A portion of the material is boiled with 4 per cent. hydrochloric acid, and pure zinc added to the solution. The precipitated metal is redissolved in acid, and the solution rendered slightly alkaline with sodium hydroxide, and tested with one drop of a solution of 5 parts of bismuth nitrate in 100 parts of nitric acid and 400 parts of water. A brown coloration is obtained in the presence of traces of tin.

The determination of substances soluble in water at 50° to 55° C. affords an indication of the presence of soap, glycerin, glucose, borax or other soluble substances sometimes added as weighting material to silk. The Milan Commission fixed a limit of 1.5 per cent. for the proportion of substances soluble in water. In this determination the dried silk is heated for thirty minutes with 10 times its weight of distilled water at 50° to 55° C. in a closed metal tube, the water being then changed and the heating continued for another thirty minutes at the same temperature.

Heermann² recommends the use of a mixture of glycerin and N-potassium hydroxide solution in equal parts as a reagent for the extraction of "monopol black" from weighted silk without injury to the fibre, as sometimes happens when alkali is used by itself for this purpose. The material is heated with this solvent to about 80° C. on the water bath, and the mixture kept at that temperature for about ten minutes. The black dyestuff is completely extracted in this way without any of the fibre being dissolved. Prussian blue may also be rapidly extracted by means of the same reagent, and the dyestuff may be reprecipitated by adding an acid to the solution.

This treatment will also effect a separation of Prussian blue from iron present in other forms in the silk (oxide, tannate, etc.). A silk weighted with Prussian blue and yielding an ash of 9.56

¹ "Bull. Soc. Ind. Mulhouse," 1906, **76**, p. 357.

² "Farber Zeit.," 1909, **20**, p. 75.

per cent., gave after extraction with glycerin-alkali solution for ten minutes, only 0·43 per cent. of ash.

In the case of silks containing (in addition to Prussian blue) tin phosphate, tin oxide, etc., Heermann recommends successive extraction of the material with glycerin-alkali solution, with cold 20 per cent. hydrochloric acid, and again with glycerin-alkali. If extraction still remains incomplete an estimation of the amount of nitrogen will then be found the best method.

Differentiation of Silk from other Fibres.—Silk is readily distinguished from vegetable fibres, including artificial silks, by emitting an odour of burnt horn when ignited, but it is not easy to recognise the difference between the smell of burning wool and burning silk.

Most of the chemical characteristics of silk have been mentioned in the preceding pages, and others are shown in the table on page 73 given by Suvern,¹ which also summarises the points of difference between ordinary and tussah silk.

Other tests for distinguishing between mulberry silk and tussah silk have been recommended by Bastow and Appleyard:—²

Reagent	Mulberry Silk	Tussah Silk
Hot 10 per cent. sodium hydroxide solution	Dissolved in 12 minutes	Dissolved in 50 minutes
Cold HCl (sp. gr. 1·16)	Dissolved very rapidly	Partially dissolved in 48 hours
Neutral ZnCl ₂ solution (sp. gr. 1·725)	Dissolved very rapidly	Dissolved slowly
Strong chromic acid solution	Dissolved very rapidly	Dissolved very slowly

*Lecomte's Method.*⁴—This is based on the fact that when the amidogen group in silk or wool is diazotised by nitric acid, the resulting compound gives characteristic colourations with various

¹ "Farber Zeit," 1900, 11, p. 283.

² "J. Soc. Dyers and Col," 1888, 4, p. 89.

³ "J. Pharm. Chem.," 1906, 24, p. 447.

Reagent	Chinese Raw Silk.	Tussah Silk.	Artificial (Chardoune) Silk
Potassium hydroxide solution, concentrated Potassium hydroxide, 40 per cent. solution	Dissolves on gently warming Acted on at 65° C. Dissolved at 85° C.	Dissolves on boiling Swells up at 75°. Dissolves at 120° C.	Unaltered Insoluble
Zinc chloride, 60 per cent. solution	Completely dissolved at 120° C.	Completely dissolved at 135° C.	Dissolves at 140° to 145° C
Copper sulphate ammonia solution ($CuSO_4$, 10 grms. ; glycerin, 10 c.c. ; 40 per cent. NH_3 , 10 c.c.)	Dissolves in 30 minutes at ordinary temperature	Scarcely attacked	Not attacked even on boiling
Cuprammonium solution	Dissolves with exception of slimy residue.	Unattacked	Unattacked even on boiling
Fehling's solution	Dissolves readily on boiling	Dissolves on boiling	Not attacked
Millon's reagent	Violet coloration on boiling	Violet coloration on boiling	No change
Iodine solution	Deep brown coloration	Faint brown coloration	Brown coloration changing to blue
Ash	0.95	1.15	1.60
Behaviour at 200° C., and loss in weight	Becomes brown and friable ; 11.15 per cent.	Scarcely altered ; 11.21 per cent	Blue-black coloration then carbonisation. Friable with difficulty ; 43 to 65 per cent.
Percentage of nitrogen	16.60	16.79	0.15
Percentage of water	7.99	8.26	10.37
Water absorbed in 48 hours, per cent.	2.24	5.0	5.24

phenols: Wool, however, contains sulphur, which will react with lead to form a black sulphide completely marking the diazo-coloration. Vegetable fibres will remain colourless in both cases.

A definite area (0.1 square cm.) of the fabric is soaked in dilute nitric acid (100 grms. per litre) and then treated gradually with constant stirring during three minutes with 30 c.c. of sodium nitrite solution (50 grms. per litre). After about ten minutes

the fragment is thoroughly washed, and cut into two equal portions.

One of these is treated for an hour with 40 c.c. of a cold solution of sodium plumbite and sodium naphtholate prepared by dissolving 50 grms. of sodium hydroxide in 500 c.c. of water, and gradually adding 25 grms. of lead subacetate solution in 300 c.c. of water. When the liquid is clear 5 grms. of β -naphthol are added and the solution diluted to a litre.

The other fragment is treated with 40 c.c. of a solution of sodium plumbite and sodium resorcinate containing 25 grms. of lead subacetate solution, 50 grms. of sodium hydroxide and 2 grms. of resoremol per litre.

After one hour's treatment both fragments are washed for fifteen minutes in running water, then immersed in dilute hydrochloric acid (5 grms. per litre) again washed for an hour, pressed between filter paper and dried in the dark. When examined under the microscope the silk fibres will appear of a rose colour, wool fibres black, and vegetable fibres colourless.

Separation of Silk from other Fibres.—The amino group in silk is apparently dissociated by various metallic basic solutions with the formation of soluble salts.

Of these solutions the most frequently used are alkaline copper oxide solution with the addition of glycerin, and an ammoniacal solution of nickel oxide.

Alkaline Copper Solution—This may be prepared by dissolving, 26.7 grms. of crystalline copper sulphate in 150 c.c. of water adding 10 grms. of glycerin, and introducing sodium hydroxide solution drop by drop until the precipitate dissolves.

Ammoniacal Nickel Oxide Solution.—Richardson¹ prepares this reagent by precipitating the nickel hydroxide from a solution of 25 grms. of nickel sulphate in 500 c.c. of water, by means of sodium hydroxide, mixing the washed precipitate with water and adding ammonia solution (sp. gr. 0.880) to make the liquid up to 250 c.c.

This reagent dissolves silk rapidly in the cold, only about two minutes being required for removing the silk from a fabric.

¹ "J. Soc. Chem. Ind.," 1893, 12, p. 427.

Under these conditions purified cotton lost 0·45 per cent., and purified wool 0·33 per cent.

For the separation of wool from plush it was found necessary to heat the material with the reagent for ten minutes under a reflux condenser. Under this treatment cotton lost 0·8 per cent. in weight.

Zinc Chloride Reagent.—Elsner¹ gives the following direction for preparing a suitable reagent:—

The weighed portion of the material is immersed two or three times for about a minute in the boiling reagent.

Under these conditions Richardson found purified cotton to lose 0·45 to 0·60 per cent., and purified wool, 1·5 to 2·0 per cent.

Wool, when present may subsequently be separated from the cotton by boiling the residue with a 2 per cent. solution of sodium hydroxide for seven minutes.

The results of comparative experiments made with these different reagents by Richardson were as follows:—

Composition of Fabric	Actually Present	Treatment with Nickel Oxide Reagent		Treatment with Zinc Chloride		Treatment with Copper Glycerin Reagent	
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silk	-	5·84	5·92	5·52	18·80		
Wool	-	76·51	76·58	80·08	64·05		
Cotton	-	17·85	17·50	14·14	17·15		

¹"Praxis des Chemikers," p. 418.

CHAPTER V.

COTTON.

Origin.—Cotton is the name given to the fine down or cellular hair which covers the seeds contained in the capsule, the fruit produced by plants of the genus *Gossypium*, belonging to the natural order *Malvaceae*.

So great is the influence of the nature of the soil and of climatic conditions upon the cotton plant that each species, when grown in different parts of the globe, has produced pronounced variations from the original type, with the result that there has long been considerable confusion as to the number of true species.

The five species described by Linnaeus have been enormously increased by some authorities, Bennet, for instance, describing over 100, while, on the other hand, Royle,¹ whose classification is accepted by Johannsen² and by Kuhn,³ concluded that there were only four true species, and that all the other might be regarded as varieties of these.

Species of the Cotton Plant.—The four fundamental species in Royle's classification, whence all the numerous varieties are said to be derived, are: (1) *G. herbaceum*, (2) *G. arboreum*, (3) *G. barbadense*, and (4) *G. hirsutum*. The plants known as *G. acuminatum* or *peruvianum* are probably derivatives of *G. hirsutum*, though some botanists regard them as belonging to a distinct species.

i. *G. herbaceum* (Linn.) is common in India, China, Japan, Arabia, Persia and Asia Minor, and is the principal Oriental species. It grows as a shrub about 20 to 45 inches in height. Most of its varieties produce

¹ "Culture and Commerce of Cotton in India," 1851, p. 151.

² "Baumwollspinnerei," 1902, p. 123. "Die Baumwolle."

yellow flowers and white soft cotton with staple of moderate length. The Chinese variety, "Nankin," which produces yellow cotton, belongs to this species, as do also the perennial Indian variety, *G. indicum*, and the short-stapled Egyptian and Smyrna varieties.

- ii. *G. arboreum* (Linn.), which occurs in India, China, Arabia, etc., is, as its name denotes, usually a tree which grows to a height of 15 to 20 feet, and is generally perennial. It produces dark red flowers.
- iii. *G. barbadense* (Linn.) is cultivated in the West Indies (Barbadoes and Bahamas) and on the coasts of the Atlantic, the varieties being annual or perennial. It reaches a height of 4 to 12 feet and produces yellow flowers, becoming purple towards the base, black seeds, and long, soft, silky fibres. The celebrated "Sea Island" cotton belongs to this species, and "Georgian Uplands" ("Bowed") is the result of cultivating that variety on the mainland. It has also been acclimatized in Egypt, Australia and the Fiji Islands. The *G. sandwichense* and *G. tahitense* of Parlatore are described by Kuhn as varieties of this species.
- iv. *G. hispidum* (Linn.), which is extensively cultivated in the United States, was probably originally indigenous to Mexico. It grows to a height of 3 to 5 feet, and is characterized by having its leaf-stalks and young-shoots thickly coated with hairs. It produces greenish-black seeds, white or pale-yellow flowers, and white or yellowish fibres. "New Orleans" and "Bourbon" cotton belong to this species, which also includes the curious variety known as "Cuba Vine," and the green-seeded cottons of Venezuela and the West Indies.
- iva. *G. acuminatum* or *peruvianum* includes the South American cotton plants, which are frequently classified as a separate species. The Brazilian variety is characterized by its curious kidney-shaped seeds;

whence its name of "Kidney" cotton. These varieties were included by Parlatoe in the species *G. religiosum* of Linnæus. They produce large-leaved yellow flowers and long, tough, white or yellowish fibres.

History of Cotton as a Textile.—There is little doubt as to the extreme antiquity of the employment of cotton as a textile material. Thus Herodotus¹ (483 B.C.) makes mention of its being used by the natives of India for clothing, and it was probably in use there centuries before his time.

In China the cultivation of the cotton plant dates back to a much more recent period than in India; for it was not until the tenth century of the present era that the first attempts were made to grow it for manufacturing purposes, and another three or four centuries passed before it began to be popular as a material for clothing. Ever since, however, there has been an increasing demand for cotton, and at the present time the Chinese are unable to supply the native looms from their own plantations, and have to import large quantities of yarn from India and Burmah.

Cotton was probably grown in Egypt at a very remote period, but there is considerable doubt whether the "cotton" mentioned by Herodotus and other early writers as being worn by the priests was not in reality linen, for all the wrapping on the mummies examined by Thomson² were composed of linen. In any case until comparatively recently cotton was only grown and used to a very limited extent. The native cotton was of poor quality, and the rise of the flourishing cotton industry of modern Egypt dates from the early part of last century, when the cultivation of a foreign variety from Bahamas was begun by a Frenchman named Jumel.

Although the ancient Greeks and Romans may have been acquainted with the use of cotton as a clothing material, the plant does not appear to have been cultivated in Greece or Italy

¹ Herodotus, m. 106: "They possess, likewise, a kind of plant which, instead of fruit, produces wool of a finer and better quality than that of sheep; of this the natives make them clothes".

² On the mummy cloth of Egypt, "Annal. Philos." for June, 1834.

until long after the Christian era. The real foundation of the cotton industry in Europe must be attributed to the Moors, who in the 10th century carried on the manufacture in Seville, Cordova and Granada, and the knowledge spread slowly from the South of Spain by way of the other Mediterranean countries to the rest of Europe.

Up to the end of the 16th century the small amount of cotton used in England was imported from Italy and the Levant, a small proportion also being derived from India, where the Portuguese had organized the industry. In 1641 the manufacture of cotton was well established in Manchester, but did not make much headway for the next century. Then, however, the invention of the spinning rollers of Wyatt and Paul (1738) and of spinning jenny by Hargreaves (1764-7) led to the rapid development of the manufacture. Warps of cotton could then be used by the weavers in place of the linen warps which had previously been found necessary for cotton goods, and the yarns could be supplied at lower prices.

Cotton was first imported into this country from India between the years 1783 and 1790, and the first importations from the United States were made about the same time.

The antiquity of the use of cotton in the new world is shown by the fact that the gauze found in tombs of the ancient Peruvians in Guacho consists of cotton. Magellan found it being used as clothing by the Brazilians, and it was seen by Columbus in the West Indian Islands.

In North America a short-stapled cotton was cultivated to a limited extent early in the 17th century, but it was not until about 1768 that the fine long-stapled variety was first grown on the islands off the coast of Carolina and in the uplands of Georgia from West Indian seed. Thence the cultivation was extended to the States on the Gulf of Mexico and subsequently to Texas. None of the cotton grown on the mainland, however, has the peculiar excellence of the "Sea Island" cotton and the pronounced superiority of the fibres of the latter over most other kinds of cotton played a considerable part in the rapid development of the American cotton industry.

Commercial Varieties of Cotton.—It has been proved experimentally that the variations produced in cotton by cultivation under different conditions are transmitted from generation to generation, and the distinctive characteristics in the fibres of different varieties attributable to peculiarities in the soil and climate thus remain fairly constant.

These differences are as a rule sufficiently pronounced for an expert to be able to distinguish between most varieties of cotton, and in some cases the differences are obvious.

The influence of particular conditions of soil and climate is illustrated by the facts that cotton grown from Sea Island seed in other parts of the world does not equal the original, and that the plant soon shows signs of degeneration.

Sea Island cotton (from *G. barbadense*) is distinguished by the length and fineness of its staple, its silky lustre, good colour, and

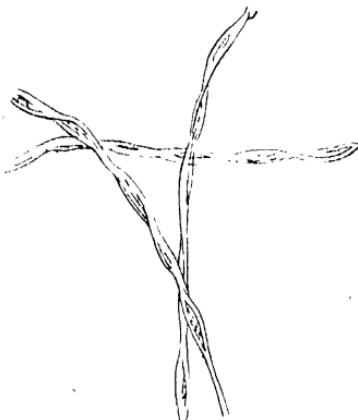


FIG. 31.—Sea Island Cotton.

the number and regularity of the twists in its fibre. In the opinion of Hanausek¹ (and his view is supported by Herbig),² the greater the number of twists in the fibre the better the

¹ "Techn. Microsk.," p. 55.

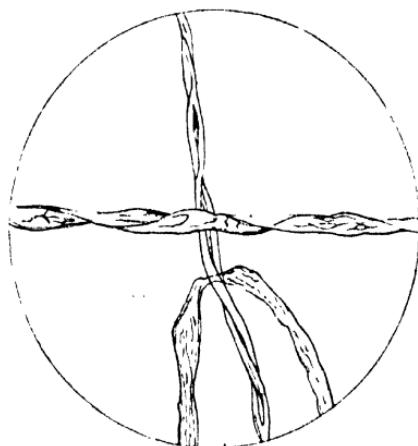
² "Zeit. ges. Textile-Ind.," 1899, iii. pp. 7-19.

quality of the cotton. This cotton is used for the very finest yarns.

Fiji cotton (*G. barbadense*) resembles Sea Island cotton, but is not so strong, while the best white Egyptian cotton known as *Gallini*, lacks its bright colour and is not quite as long or silky.

Algerian cotton ranks with Egyptian as regards length of staple and quality.

The *Brazilian* and *Peruvian* cottons (*G. peruvianum*) are harsher and more wiry than the white Egyptian, with which in practice they are frequently mixed. The fibres are moderately strong and range in colour from dull white to dull gold.



• FIG. 32.—Brazilian Cotton

Of the American varieties (apart from Sea Island) the best known are *Uplands*, *Mobile*, *Terre*, and *Orleans*. The fibres are soft, pliable, and moderately strong, but only about half the length of those of the Sea Island cotton. They are used alone and in admixture with Egyptian and Brazilian kinds in coarser yarns.

The best Indian variety, *Himachal*, has strong fibres of golden tint, about equal to *Orleans* in length; the poorest *Scinde* is dull white and contains staples only about half an inch in length. Indian cottons are frequently dirty, and contain a large proportion of broken fibres.

Australian cotton (*G. barbadense*) of which little is now grown

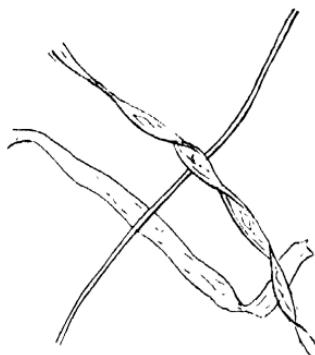


FIG. 33.—Orleans Cotton.

resembles white Egyptian cotton in length of staple and other characteristics.

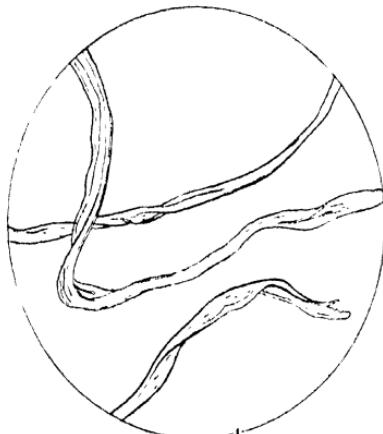


FIG. 34.—Bengal Cotton.

The native *African* varieties vary greatly in the length and regularity of their fibres but are usually inferior, although good

results have been obtained with Egyptian and American varieties on African soil.

Smyrna cotton (from *G. herbaceum*) is dull white in colour, and is usually somewhat shorter than brown Egyptian (also from *G. herbaceum*). The cotton grown in small quantity in Italy comes between the American and Indian varieties as regards the length of its staple. One variety is red.

Chinese cotton is characterised by the brightness of its colour and its short staple. Little of it is exported.

Structure of the Cotton Fibre.—The long soft cellular hairs which coat the seeds in the capsule of the cotton-plant differ considerably in structure in the unripe state and at maturity, as was first pointed out by Crum.¹

At the earliest stage the fibre when examined under the microscope appears flat and without much indication of the lumen or central canal, which is gradually developed in the

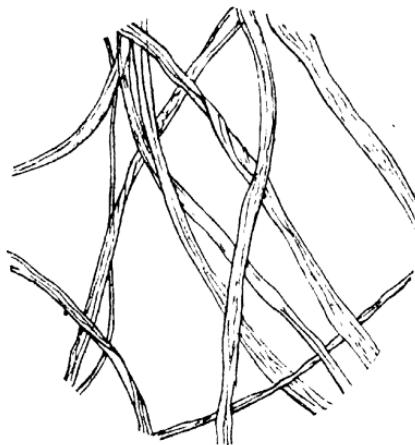


FIG. 35.—Commercial Cotton Wool

ripening cotton. The outer membrane is also excessively thin and transparent, and the fibre itself apparently lacks the tubular structure and shows very few of the characteristic twists of the fully-developed fibres.

¹ "J. Chem. Soc., " 1863, i. p. 404

In the ordinary cotton of commerce the usual microscopic appearance of the fibres is that of flattened tubes with numerous cork-screw like twists, usually from left to right, along their length; for the process of drying causes shrinkage, so that the fibres appear much flatter than in the freshly-gathered state.

The various stages of ripeness described by Crum, however, may still be differentiated in the dried fibres, viz., (i.) unripe fibres; (ii.) half-ripe fibres, and (iii.) ripe fibres. Typical examples of these are shown in Fig. 36, and stages intermediate to these may easily be found.



FIG. 36.—Types of Cotton Fibres.

1. Glassy Dead Structureless Fibre.
2. Thin Transparent Flat Unripe Fibre.
3. Half-ripe Fibre with Thin Cell Wall.
4. Mature Ripe Fibre, with Full Twist and Thick well-defined Cell Wall.

“Dead Cotton.”—In addition to the fibres in the various stages of ripeness fibres somewhat resembling those of the first stage and known as “dead cotton” are of common occurrence. In these the characteristic twists are hardly perceptible, and there is little sign of the lumen. These are found both in the unripe capsule and in cotton that has been left too long upon the plant.

Another form of “dead cotton” has a transparent apparently structureless form, somewhat resembling the fibre of

silk, and seems to be the result of factors such as weather conditions, the health of the plant, etc. According to Kuhn, the coarser the cotton the greater the proportion of dead fibres. This is to be attributed to such fibres drawing more juice from the seed-nucleus, which thus becomes impoverished before the complete development of all its fibres. Thus "dead cotton" is much more common in certain Indian varieties than in the long-stapled cottons of Egypt and Sea Island.

It often causes considerable trouble in the dyeing processes owing to the fact that it resists the action of dyestuffs which have an affinity for ordinary cotton.

Dead or unripe fibres have been shown by Haller¹ to differ from ripe fibres in their behaviour towards chemical reagents. Thus, a potassium iodide solution of iodine imparts a dark, yellowish-brown colour to the latter, whereas the former remain light yellow. Similarly on treatment with zinc chloride solution of iodine dead fibres give a blue coloration more rapidly than the ripe fibres. They also show pronounced differences in their behaviour with various dyestuffs.

The differences in the various stages of fibres are also plainly discernible in transverse section, those of young unripe cotton appearing almost as a single line with but little indication of a central opening. This becomes more manifest in the maturing cotton, and in the fully-grown fibres approaches more closely the cylindrical form.

Cell Walls.—Kuhn concludes that the walls of the cotton fibre are made up of fibrillæ, which attach themselves to the primary membrane in a spiral direction, and he attributes the absorptive power of cotton for dyestuffs to permeable spaces being left between the these fibrillæ.

Crum (loc. cit. p. 5) was unable to detect any signs of apertures in the surface of the fibre, but it has been demonstrated by de Mosenthal² that with the aid of high powers many of the striations may be seen to consist of stomata in oblique rows,

¹ "Chem. Zeit," 1908, **32**, p. 838.

² "J. Soc. Chem. Ind.," 1904, **xxiii**, p. 292.

and that these may also be observed in particles of cuticle that separate on treating the fibre with cuprammonium solution. These pores and stomata may be rendered more distinct by stretching the fibre and treating it with silver nitrate solution.

De Mosenthal also confirms the work of previous observers in finding that the cotton fibre consists of (a) an outside cuticle or membrane; (b) an inner cuticle or membrane; and (c) intercuticular substance between the two cuticles, constituting 80 to 90 per cent. of the fibre.

Schweitzer's reagent (ammoniacal solution of copper oxide) attacks the intercuticular substance first, and the undissolved cuticles may thus be separated by filtration through glass wool.

The intercuticular substance was found by de Mosenthal to consist of minute spherical granules about $1\text{ }\mu$ in diameter, closely packed together, and retained in position by the cuticles.

Wild Cotton.—According to Kuhn (loc. cit. p. 122) cultivation of the cotton plant has the effect of reducing the tendency of the fibrillæ to produce a spiral formation, and they become more parallel with the axis of the fibre, which grows more elastic and assumes the characteristic twists of commercial cotton.

The more distinct the spiral structure the less the tendency to twist, and the relapse of a cultivated variety into a wild state is accompanied by a defective production of twists.

In wild cottons, in which the twists are lacking, the spiral formation of the secondary deposit is readily seen. The fibres of wild cotton are so rigid and inelastic as to be unsuitable for spinning.

Dimensions of the Cotton Fibre.—The measurements given by different authorities are in some cases open to the objection that they refer only to the crop of a single year, whereas both the length and diameter of the fibre are considerably influenced by the conditions of harvest, being longer and more regular in a good year, and *vice-versa*.

Although, as was found by Bowman,¹ the average dimensions of the fibres of different varieties of cotton need not vary greatly

¹ "Structure of Cotton Fibre," 1881, p. 19.

over a number of years, yet the published figures show that considerable variations do occur.

In the following tables we have collated the measurements of different observers, and for the purpose of comparison have calculated the figures into the corresponding millimetres or inches.

With regard to the diameter of the fibres the measurements obviously vary with the position at which they are taken, and the tapering point is much narrower than the main portion of the staple.

Von Höhnel found the diameters in micromillimetres of a single fibre measured successively from the base to the tip to be as follows: 17, 25, 29, 25, 21 and 8 μ .

The mean diameter of all the varieties examined by Déschamps¹ was 21.6 μ . He classifies commercial cotton into (a) fine cotton with fibres up to 20 μ , (b) ordinary cotton with fibres from 20 to 23 μ , and (c) coarse cotton with fibres of 23 μ and over in mean diameter.

¹ "Le Coton," p. 165.

LENGTH OF COTTON STAPLES.

DIAMETER OF FIBRES

in Micromillimeters (μ) and Fractions of an Inch (1 μ = 0.000039 inch).

	Déschamps (Micromillimeters).	In μ	Alean (Inches).	In μ	Monie, (Inches).
Sea Island	16.5	0.00064	6.6-13.3	0.00025-0.00052	3.5 0.000135
Fiji	17.2	0.00067			16.3 0.000637
Egyptian	19.4	0.00076			17.3 0.000675
Algerian			10.25	0.00039-0.00097	
U.S.A.	21.0	0.00062	10.22-2	0.00039-0.00057	
U.S.A.	Bourbon	22.2	0.00087		
	Orleans				19.3 0.000757
West Indian					19.7 0.000769
Brazilian					
Pernambuco	28.0	0.00109			20.1 0.000787
Maranhão					20.1 0.000787
Peruvian	21.5	0.00084	13.3-20	0.00025-0.00078	20.0 0.000781
Indian					
Hungunhat				0.00039-0.00129	21.3 0.000833
Dhollerah			10.33-3		21.7 0.000847
Brocach	22.5	0.00088		0.00055-0.00118	21.3 0.000833
Comptah			14.2-30.3		21.7 0.000847
Bengal	25.3	0.00098			22.1 0.000869
W. Madras	22.5	0.00088	11.1-16.6	0.00043-0.00065	21.3 0.000833
N. Madras	20.0	0.00078	11.1-16.6	0.00043-0.00065	
Seinde			13.3-25	0.00025-0.00097	21.0 0.000819
African					19.7 0.000769
Smyrna	26.2	0.00122			
Chinese			25.27	0.00097-0.00105	

Déschamps (loc. cit. p. 174) accepts the following figures given by Evan Leigh as typical of the dimensions of the various kinds of cotton:—

DIMENSIONS OF TYPICAL KINDS OF COTTON.

Origin.	Description.	Length.			Diameter.		
		Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
United States	New Orleans or Uplands	29.46	22.35	29.46	24.6	14.7	19.6
Sea Island	Long-stapled	45.72	35.81	40.86	20.8	11.6	16.2
S. America	Brazilian	33.27	26.16	29.71	24.3	15.7	20.0
Egypt	Egyptian (Jumel)	38.60	33.02	35.81	18.2	14.9	16.6
India	Indigenous or Native	25.90	19.55	22.60	26.4	16.4	21.4
India	From American Seed	30.73	24.41	37.43	25.2	16.6	20.9
India	From Sea Island or Egyptian Seed	41.91	34.54	38.10	21.9	15.1	18.5

1 millimeter (mm.) = 0.03937 inch.

1 μ = 0.000039 inch.

CHEMICAL COMPOSITION OF COTTON.

About 91 per cent. of the fibre consists of cellulose, the other constituents being water, mineral matter, albuminous substances, traces of pectic acid and fatty acids, colouring matter, and the so-called cotton-wax.

The percentage composition of ten samples of Sea Island and Upland cotton quoted in a publication of the U.S.A. Department of Agriculture¹ was as follows:—

	Water	Ash	Nitrogen.	Phosphoric Acid (P_2O_5).	Potassium Oxide	Calcium Oxide.	Magnesium Oxide.
Minimum	4.72	0.93	0.20	0.05	0.28	0.07	0.02
Maximum	6.77	1.80	0.54	0.18	0.85	0.48	0.17
Average	6.07	1.37	0.34	0.10	0.46	0.19	0.08

¹ "Bulletin," No. 33, 1896, p. 90.

Water.—Freshly-gathered cotton contains more moisture than that which has been stored for some time, but at ordinary temperatures it always retains some water which may be regarded as a constituent part of the fibre. According to Kuhn¹ this water of constitution amounts to about 2 per cent. If it be expelled at 105° C. the fibre feels harsh and brittle, and loses its pliability.

The proportion of water ordinarily present in cotton largely depends upon the moisture in the air, the fibres possessing great absorptive powers.

In commerce the normal proportion of water in cotton is taken as 8.5 per cent., and sales are made on this basis the special method of determining the moisture being termed "conditioning" (see p. 32).

Cellulose.—The substance constituting the main portion of cotton is a carbohydrate, or more probably a mixture of carbohydrates which is commonly spoken of as a chemical individual.

Its elementary composition corresponds to the formula $(C_6H_{10}O_x)_n$, the value of x not being known.

It may be prepared by treating cotton wool successively with potassium hydroxide solution, hydrochloric acid, water, alcohol and ether, so as to extract the other constituents.

It is soluble in cuprammonium (Schweitzer's reagent) from which acids reprecipitate it in the form of an amorphous white powder.

When dissolved in concentrated sulphuric acid and the solution diluted and boiled cellulose is hydrolysed with the formation of dextrin and dextrose. It is soluble in a more concentrated sulphuric acid (specific gravity, 1.5 to 1.6), and the solution on dilution with water gives a precipitate of a colloidal modification of cellulose termed *amyloid*, which gives a blue coloration with iodine.²

In the light of De Mosenthal's³ experiments it is doubtful

¹ "Die Baumwolle," p. 131.

² *Vegetable parchment* is made by immersing unsized paper in dilute sulphuric acid (1:1), so that the surface becomes coated with amyloid.

³ "J. Soc. Chem. Ind.," 1907, chap. xxvi. p. 4.

92 FIBRES USED IN TEXTILE AND ALLIED INDUSTRIES.

whether cellulose is optically active, though nitrated cotton is so.

The solution of cellulose in cuprammonium is attributed by Cross and Bevan¹ to the preliminary formation of a soluble gelatinous hydrate induced by the presence of the copper, and analogous reactions take place when cellulose is dissolved by a boiling solution of zinc chloride or a cold solution of the same salt containing hydrochloric acid. These solutions are of technical importance in the manufacture of artificial silk.

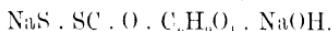
Alkali Cellulose.—According to Vieweg cellulose combines with caustic alkali to form a definite compound $(C_6H_{10}O_5)_n$, $NaOH$, the value of n , varying with the strength of the alkali solution (see *Mercerised Cotton*).

Oxycelluloses.—Boiling nitric acid (sp. gr. 1.1 to 1.3) transforms cellulose into oxycellulose, a white flocculent substance which is gelatinized on the addition of water through the formation of a hydrate. Similar compounds are produced by other oxidising agents, such as ozone, hydrogen peroxide, and alkaline hypochlorites.

Hydrocelluloses.—It is suggested by Cross and Bevan that in view of the existing confusion of terms the name *hydrocelluloses* should be restricted to hydrolytic products of the action of acids upon cellulose, while the name *hydracelluloses* should be given to the products of the action of alkalies.

Viscose (alkali-cellulose thiocarbonate).—When cellulose that has been converted into alkali-cellulose by the action of caustic alkali is treated with carbon bisulphide combination takes place and a soluble xanthogenate, named *Viscose* by its discoverers, Cross and Bevan,² is produced.

This compound is formed by the interaction of one molecule of cellulose $(C_6H_{10}O_5)_n$, two of sodium hydroxide ($2NaOH$) and one of carbon bisulphide (CS_2), and its general empirical formula is given by Cross and Bevan as



“Cellulose,” 1895.

“Researches on Cellulose,” n. p. 142

Viscose is soluble in water, and its solution is used as the basis in several processes of manufacturing artificial silk.

Action on Fehling's Solution.—Pure cellulose has only a slight reducing action upon Fehling's solution, while oxycellulose and nitrocellulose cause considerable reduction, so much so that the reaction may be employed as a test for over-bleaching in cotton and other cellulose fabrics (see p. 102).

Schwalbe¹ has devised the following method of determining the amount of reduction so as to obtain comparable figures, the "copper values" representing the amount of copper reduced, calculated upon the dry cellulose: About 3 grams of the air-dried substance are boiled for fifteen minutes under a reflux condenser with 100 c.c. of Fehling's solution and 200 c.c. of water, the flask being meanwhile constantly shaken. The liquid is filtered while hot, the residue washed with boiling water and heated on the water-bath for fifteen minutes with 30 c.c. of 6.5 per cent. nitric acid, and the dissolved copper determined, preferably by an electrolytic method.

The following "copper values" were thus obtained: Surgical cotton wool, 1.64, 1.8; bleached mercerised yarn, 1.9, 1.6; artificial silk (Glanzstoff), 1.1; hydrocellulose, 5.2, 5.8; parchment paper, 4.2; bleached sulphite wood-pulp, 3.9; over-bleached wood-pulp, 19.3; oxycellulose (action of bleaching powder on filter-paper), 7.9; and bleached cotton rag, 6.5.

Hydrocelluloses formed by non-oxidising acids gave copper values ranging from 1.9 to 8.8, while oxycelluloses varied from 7.6 to 34.9. The value of mercerised cotton (cellulose hydrate) was only slightly higher than that of cellulose. The low reducing action of parchment papers (1.9 to 4.2) is to be attributed to the fact that strong acids hydrate cellulose considerably before their hydrolytic action has proceeded far.

Vignon² describes the following method of preparing oxy-cellulose from cotton purified by successive treatment with boiling 1 per cent. sodium carbonate solution, boiling 1 per cent. potassium hydroxide solution, cold 1 per cent. hydrochloric

¹ "Ber. d. d. chem. Ges." 1907, xl, pp. 1347, 4523.

² "Bull. Soc. Chim." 1898, p. 917.

acid and cold sodium carbonate solution. The cotton is then thoroughly washed with water and alcohol and dried, 30 grms. immersed in a hot solution of 150 grms. of potassium chlorate in 3 litres of water, and 125 c.c. of hydrochloric acid gradually added. The liquid is heated for one hour, after which the cotton residue is removed, washed, first with water and then with alcohol, and dried in the air.

The oxy cellulose thus obtained is composed of very short fibres which turn yellow when heated at 100° C. Treated with boiling solutions of safranine and methylene blue it absorbs 0.007 and 0.006 grm. respectively, whereas ordinary cellulose only absorbs 0.000 grm. and 0.002 grm. per grm. of material (cf. "Action of Hypochlorites on Cotton," p. 102).

It dissolves in an aqueous solution of potassium hydroxide, forming a yellow liquid which reduces Fehling's solution and gives a white precipitate with acids. It gives a violet coloration with Schiff's reagent.

Cellulose forms other salts, such as nitrates, acetates, formates, etc., which are of technical importance. The details of these and other compounds of cellulose, in so far as they bear upon the scope of the present work, are given in the following section dealing with the chemical reactions of cotton, and in those dealing with *Mercerized Cotton* and *Artificial Silks*. For further particulars the reader may be referred to the classical work of Cross and Bevan¹.

Cotton Wax.—The fibres of the seed hairs of the cotton plant are coated with a wax-like layer, the quantity depending on such factors as the kind of the plant, state of ripeness, nature of the soil, etc. This wax, which constitutes from 0.3 to 0.5 per cent. of the commercial cotton, may be separated by boiling the fibres with concentrated sodium hydroxide solution, adding a slight excess of sulphuric acid, and washing the insoluble light brown deposit. It melts at about 86° C., solidifies at 81° to 82° C., and appears to resemble the similar *Flax wax* in composition.

Endochrome.—The colouring matter within the fibre of the

¹ "Cellulose," 1895; "Researches on Cellulose," i. (1895) and ii. (1906).

cotton varies in quantity with the variety of cotton. It is deposited in the walls of the fibre, not in the lumen, and is most pronounced toward the outer ends.

Schunck isolated two colouring matters from American, Indian, and Nankin cotton,¹ which differed from one another in their solubility in alcohol. The colouring matters from the Nankin cotton had the following composition:—

	Carbon Per cent.	Hydrogen Per cent.	Nitrogen Per cent.	Oxygen Per cent.
A.	58.22	5.42	3.73	32.63
B.	57.70	5.60	4.99	31.71

The ash of dark-coloured cotton does not contain more iron than white varieties (Kuhn²).

Mineral Matter.—One of the earliest analyses of the mineral matter in cotton was that made by Ure in 1825 of a sample of Sea Island cotton. The total amount of ash was about 1 per cent., and had the following composition. Potassium carbonate, 44.8; potassium chloride, 9.90, potassium sulphate, 9.30; calcium phosphate, 9.00; calcium carbonate, 10.60; magnesium phosphate, 8.40; ferric oxide, 3.00; and alumina and loss 5.0 per cent.

A specimen of Orleans cotton examined by Shephard yielded 0.92 per cent. of ash with the following composition: Sand, dust, and other impurities, 12.88; potassium carbonate, 44.19; calcium phosphate, 25.44, calcium carbonate, 8.87; magnesium carbonate, 6.85; silica, 4.12; alumina, 1.40; potassium sulphate, 2.70; potassium chloride, magnesium chloride, potassium phosphate, traces of iron, and loss, 6.43 per cent.

Davis, Dreyfus, and Holland,³ found the foreign mineral matter (sand, dust, etc.) in bales of ten different varieties of cotton on arrival at Liverpool to range from 1.25 per cent. (Sea Island) to 6.22 per cent. (Dhollerah).

Average samples from these ten varieties, mixed and ignited, yielded ash of the following composition: Potassium carbonate, 33.32; potassium chloride, 10.21; potassium sulphate, 13.02;

¹ "Chem. News," 1868, xviii. p. 118; 1874, xxix. p. 5.

² *Loc. cit.*, p. 138. ³ "Sizing and Mildew in Cotton Goods," p. 16.

sodium carbonate, 3·35; magnesium phosphate, 8·73; magnesium carbonate, 7·81; calcium carbonate, 20·26; and iron oxide, 3·40 per cent.

Typical specimens of different kinds of cotton examined by the present writers gave the following results:—

Cotton	Moisture	Mineral Matter, including Sand		Phosphoric Acid as P_2O_5
		Per cent	Per cent	
Sea Island	7·83	2·1	0·22	
Orleans	7·7	2·05	0·18	
Pernambuco	8·85	2·08	0·37	
Indian (Oomra)	7·27	2·86	0·23	
Indian (Bengal)	7·89	3·3	0·15	

Grace-Calvert¹ found the amount of phosphoric acid (P_2O_5) in the ash to vary considerably in different kinds of cotton, the following figures being obtained: New Orleans, 0·049; Egyptian, 0·055; Bengal, 0·055; Surat, 0·027; Carthagena, 0·035; Maceo, 0·05; and Cyprus, 0·05 per cent.

The sample of Pernambuco cotton examined by us contained the following constituents in its ash: Silica and sand, 12·5; chlorine, 2·5; iron and aluminium oxides, 10·7; calcium, 2·12; magnesium, 0·77; alkali metals (as potassium), 19·5; phosphoric acid, 17·2; and sulphuric acid (SO_4), 9·22 per cent.

Nitrogen.—Determinations of the amount of nitrogen in two samples of raw Egyptian cotton examined by Schindler² gave 2·56 and 2·50 per cent, respectively; when the material was boiled for eight hours with a solution of sodium hydroxide the nitrogen was reduced to 0·066 and 0·064 per cent. Bleached cotton is not tinted so deeply as raw cotton by an acid solution of safranine, and according to Haller this is due to the albuminoid matter (removed in the bleaching process) acting as a mordant for the dyestuff.

Action of Reagents on Cotton.—*Iodine* colours cotton yellow, but the colour is readily removed by washing with water. The

¹ "J. prakt. Chem.," 1869, p. 122; "Comptes Rend.," 1867, lxxv. p. 1150.

² "J. Soc. Dyers and Col." 1908, 24, p. 106.

addition of dilute sulphuric acid changes the yellow colour to deep blue.

Iodine in Zinc Chloride Solution gives a deep violet blue coloration with cotton. Mercerized cotton (q.v.) may be distinguished from ordinary cotton by means of the above reagents.

Cuprammonium Solution (*Schweitzer's Reagent*).—This is a

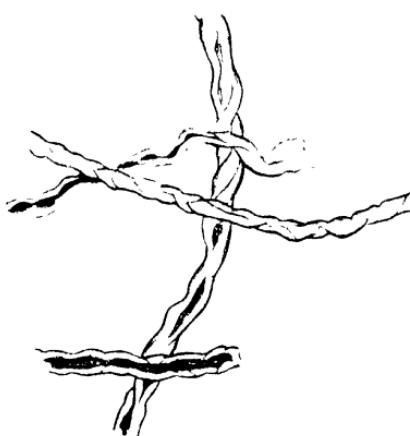


FIG. 37.—Cotton after Treatment with Cuprammonium Solution.

solution of copper oxide in ammonium hydroxide, and may be prepared by dissolving 10 grammes of copper sulphate in 100 c.c. of water, adding a solution of 5 grammes of potassium hydroxide in 50 c.c. of water, washing the precipitate, and dissolving it in a 20 per cent. solution of ammonia until a saturated solution is obtained.

On treating cotton with this reagent the fibres swell up, and eventually the intercuticular substance is dissolved before the cuticles are attacked (p. 86), the cuticular cellulose being left in the liquid in the form of insoluble flakes.

The process of solution is very slow, especially in the case of certain kinds of cotton, but previous treatment of the fibres with caustic alkali, as in the mercerizing process, greatly accelerates the action of the solvent, the cellulose hydrate produced being much more soluble than ordinary cellulose.

A solution of cotton or other form of cellulose in cuprammonium is used as the starting-point in the manufacture of certain varieties of artificial silk, e.g., Pauly's silk and Linkmeyer's silk. It is also employed in rendering cotton fabrics waterproof (*Willesden canvas*), the material passed through it becoming coated with a deposit of relatively impervious cellulose.

The addition of dilute caustic alkali solution to the cuprammonium solution precipitates a copper-alkali-cellulose, $C_{12}H_{20}O_{10}Na$, which is dissociated by water, and from which the copper can be removed by means of acids.

Zinc Chloride.—Cotton, like other forms of cellulose, is dissolved by a hot aqueous solution of zinc chloride, or by a cold solution to which hydrochloric acid has been added. Both destroy the structure of the fibre, and, as de Mosenthal has shown, fragments of cuticle are not found among the cellulose after reprecipitation by alcohol or acetone.

Caustic Alkalies.—In concentrated solution caustic alkalies dissolve the cuticular cellulose, leaving the latter as part of the normal cellulose of the fibre (Haller¹) (cf. *Mercerized Cotton*).

The cellulose of the fibre is generally considered to combine with the alkali to form a compound, to which Vieweg² assigns the formula $(C_6H_{10}O_5)_nNaOH$. The factor n varies with the strength of the alkali. According to Schalbe³ two distinct points may be observed in the absorption curve corresponding to compounds with the respective molecular ratios (a) $(C_6H_{10}O_5)_2NaOH$ and (b) $(C_6H_{10}O_5)_22NaOH$.

"Alkali cellulose" $C_{12}H_{19}O_{10}Na$ is described by Schwalbe as a definite compound capable of combining with more alkali until eventually the compound $C_{12}H_{19}O_{10}Na_2NaOH$ is produced.

In dilute solutions of alkalies "alkali cellulose" is stated to undergo hydrolysis.

Gladstone⁴ concluded that cellulose combined with sodium

¹ "Zeit. Farb. Ind.," 1907, vi, p. 125.

² "Papier Zeit.," 1907, xxxii, pp. 130, 174.

³ "Ber. d. d. Chem. Ges.," 1907, xl, p. 3876.

⁴ "J. Chem. Soc.," 5, p. 17.

hydroxide to form a soda cellulose, with a composition corresponding to the formula $(C_6H_{10}O_5)_2NaOH$

Vieweg¹ also found that cotton absorbed sodium hydroxide from a solution containing 16 per cent. of caustic alkali to form a compound of the same formula, while from solutions containing more than 35 per cent. of sodium hydroxide the cellulose compound had a composition corresponding to the formula $(C_6H_{10}O_5)_2(NaOH)_2$

In the more recent experiments of Hubner and Teitscher² it was found that the maximum absorption of sodium hydroxide, not subsequently removable by washing with absolute alcohol, occurred at a strength of 40° Tw., while somewhat less alkali was taken up from stronger solutions.

In their opinion there is no evidence of the existence of distinct chemical compounds, or soda-celluloses, as inferred by Gladstone and by Vieweg.

Action of Nitric Acid.—Dilute nitric acid (specific gravity,

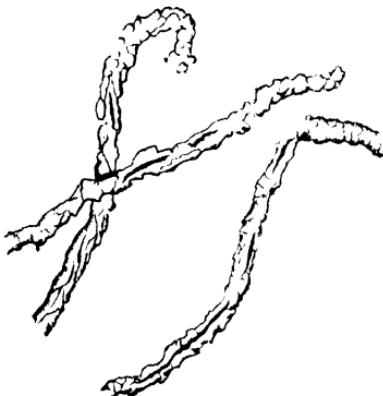


FIG. 38.—Cotton Nitrated with Dilute Nitric Acid

1:3) oxidizes cotton at 80° to 100° C. with the formation of oxy-cellulose. When treated with strong nitric acid (specific gravity,

¹ "Ber.," 1907, **40**, p. 3876.

² "J. Soc. Chem. Ind.," 1909, **28**, p. 643.

1·42) cotton assumes a parchment-like appearance and is rendered more combustible, a reaction similar to that produced by sulphuric acid taking place. Examined under the microscope a large proportion of the fibres will be seen to have been straightened out, and to show corrugations where the twists previously occurred.

The cellulose is partially converted into one or more nitric esters, and the nitration is rendered more complete by the addition of sulphuric acid to act as a dehydrating agent.

The degree of nitration increases with the strength of the nitric acid used, and definite nitrates have been described. Thus Eder¹ separated the following compounds which he regarded as definite entities:—

		Formula	Nitrogen Per cent
Hexa-nitro-cellulose	- - - - -	$C_{12}H_{11}O_4(O, NO_2)_6$	14·14
Penta-nitro-cellulose	- - - - -	$C_{12}H_{13}O_3(O, NO_2)_5$	12·75
Tetra-nitro-cellulose	- - - - -	$C_{12}H_{15}O_2(O, NO_2)_4$	11·11
Tri-nitro-cellulose	- - - - -	$C_{12}H_{17}O_2(O, NO_2)_3$	9·15
Di-nitro-cellulose	- - - - -	$C_{12}H_{19}O_2(O, NO_2)_2$	6·76

Of these the hexa-nitro-cellulose is insoluble in a mixture of ether and alcohol, and forms the ordinary *gun cotton*, while the other compounds dissolve in that solvent, and occur in *collodion cotton*.

Vieille² prepared intermediate compounds, and his list of nitrates is adopted by Lunge³:—

		Formula	Nitrogen Per cent
Dodeca-nitro-cellulose (old tri-nitro-cellulose)	- - - - -	$C_{21}H_{20}O_2(NO_2)_{12}$	14·16
Endeoca-nitro-cellulose	- - - - -	$C_{21}H_{20}O_2(NO_2)_{11}$	13·50
Deca-nitro-cellulose	- - - - -	$C_{21}H_{20}O_2(NO_2)_{10}$	12·78
Ennea-nitro-cellulose	- - - - -	$C_{21}H_{20}O_2(NO_2)_9$	11·98
Octo-nitro-cellulose (old di-nitro-cellulose)	- - - - -	$C_{21}H_{20}O_2(NO_2)_8$	11·13
Hepta-nitro-cellulose	- - - - -	$C_{21}H_{20}O_2(NO_2)_7$	10·19
Hexa-nitro-cellulose	- - - - -	$C_{21}H_{20}O_2(NO_2)_6$	9·17
Penta-nitro-cellulose	- - - - -	$C_{21}H_{20}O_2(NO_2)_5$	8·04
Tetra-nitro-cellulose (old mono-nitro-cellulose)	- - - - -	$C_{21}H_{20}O_2(NO_2)_4$	6·77

¹ "Ber. d. d. Chem. Ges.," xiii, p. 169.

² "Comptes Rend.," xcv, p. 132.

³ "J. Amer. Chem. Soc.," 1901, xxiii, p. 527.

The lower nitrates, up to deca-nitro-cellulose, may be produced by the action of nitric acid alone, while the four highest are the product of the simultaneous action of concentrated nitric and sulphuric acids.

It is held by some chemists, however (e.g. Guttmann¹ and de Mosenthal²); that these definite degrees of nitration do not exist, but that the percentage of nitrogen absorbed passes continuously from the lowest stage to the highest.

The difference in the solubility of cotton in different stages of nitration in a mixture of alcohol and ether need not, as de Mosenthal points out, indicate that there are definite nitrates containing different proportions of nitrogen; for within certain limits it is possible to prepare specimens of nitrated cotton containing the same percentage of nitrogen, one of which is soluble and the other insoluble in alcohol-ether.

On the other hand, Divers³ regards this as a proof of the existence of distinct nitrates, for in his opinion both these nitro-cottons would be mixtures, one consisting of a mixture of cellulose in a high state of nitration with low nitrated cellulose, and the other of nitro-celluloses more nearly approaching each other.

Appearance in Polarized Light—The fibres gradually change in the course of nitration in their appearance in polarized light. Chardonnet⁴ found that the fibres of cotton nitrated up to 7 per cent. of nitrogen were all brilliant, though some showed signs of contraction; from 7 to 9 per cent some appeared iridescent, from 9 per cent. to 11.25 per cent. the colours passed through grey, yellow, and orange; whilst from 11.28 per cent. onwards they appeared first colourless, then successively violet, dark blue, and finally light blue.

Liebschutz⁵ found that the tetra-nitrate (11.11 per cent. of nitrogen) appeared yellow in polarized light; the penta-nitrate (12.75 per cent.) blue; and the hexa-nitrate (14.14 per cent.) grey.

¹ "Chem. Zeit," 1901. ² "J. Soc. Chem. Ind.," 1904, xxiii, p. 294.

³ "J. Soc. Chem. Ind.," 1901, xxiii, p. 297.

⁴ "Die Kunstliche Seide," p. 25. ⁵ "Mon. Scientif.," 1891, p. 119.

Lunge and Weintraub¹ were unable to confirm this, and considered it impossible to distinguish between the penta- and hexa-nitrate in this way.

De Mosenthal² shows that the colours in polarized light depend largely on the method and conditions of nitration, and only uses polarized light as a means of distinguishing between ordinary and nitrated fibres, and not for differentiating degrees of nitration.

Action of Sulphuric Acid.—Dilute sulphuric acid (sp. gr. 1.5 to 1.6) gelatinizes the fibres of cotton, forming *amyloid* $n(C_{12}H_{22}O_{11})$ (see p. 91). The concentrated acid dissolves them, forming a series of cellulose sulphates, characterized by progressively increasing capacity for reducing Fehling's solution. On boiling the aqueous solutions of the free acids hydrolysis takes place.

Action of Hydrochloric Acid.—Cotton is disintegrated both by gaseous hydrochloric acid and its aqueous solution into a white powder resembling amyloid, and having, according to Girard, the composition $n(C_{12}H_{22}O_{11})$ (Girard's *hydrocellulose*, Witz's *hydracellulose*).

Action of Hydrofluoric Acid.—The product formed by the action of hydrofluoric acid upon cotton is a tough and waterproof substance which finds a technical application in the manufacture of the carbon filaments for electric lamps and as an insulating material.

Action of Hypochlorites.—At the ordinary temperatures cotton fibres are not much affected by dilute solutions of alkali hypochlorites (up to 0.5 Be.), but at a higher temperature, or too great a concentration, or under the influence of air or light, the fibres become disintegrated through the formation of oxy-cellulose.

Examination of Bleached Fabrics.—This over-oxidation in the bleaching processes has been exhaustively studied by Witz,³ who shows that the holes that sometimes occur in bleached

¹ "Zeit angew. Chem.," 1899.

² "J. Soc. Chem. Ind.," 1907, xxvi. p. 444.

³ "Bull. Soc. Ind. Rousen," 1882, x. p. 416; 1883, xi. p. 169.

fabrics may be produced by the unequal action of the bleaching powder. The oxidized cellulose formed has a greater affinity for

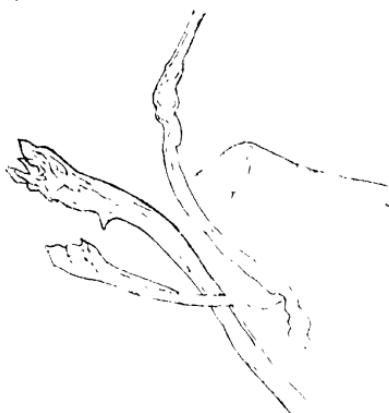


FIG. 39.—Cotton after Treatment with Sodium Hypochlorite Solution.

basic dyestuffs, so that on treating the damaged fabric with a dilute solution of e.g. methylene blue, the parts immediately surrounding the holes are dyed a much darker colour than the rest of the material. Among other dyestuffs thus attracted by oxycellulose are saffron red, fuchsine red and Bismark brown, while of dyestuffs which are repelled the following are typical: Diphenylamine blue, induline blue, eosine, and indigo carmine.

In applying the tests to textile fabrics portions of the material are treated for about twenty minutes with 0.05 to 0.1 per cent. solutions of methylene blue and diphenylamine blue. When chloride of lime was the bleaching agent the following preliminary treatment should be applied (Cross and Bevan).¹ The material should be thoroughly washed, treated for thirty minutes with cold dilute nitric acid (2° B), again washed, treated with boiling sodium bisulphite solution (1° B.) for fifteen minutes, washed, treated with dilute hydrochloric acid (2° B) for thirty minutes, and finally washed thoroughly with water.

¹ "J. Soc. Chem. Ind." 1884, in, p. 206.

Cotton fibres oxidized by hypochlorites are rendered more opaque and contracted in length by about 12·5 per cent. Examined under a magnification of 200 diameters they show fewer fibrillæ at the point of fracture, which is to be attributed to the disintegration of the fibre.

Vétilart¹ points out that whereas ordinary cotton treated with iodine solution gives a yellow coloration changed to blue by sulphuric acid, oxidized cotton gives an immediate blue colour, which is destroyed by sulphuric acid.

Philp² has shown that cotton goods that have been bleached by chloride of lime without being protected against the action of the air and subsequently hot-calendered, may have yellow or brown stains which fade to a faint yellow on exposure. The presence of oxycellulose in these may be detected by heating the material (after removal of dressing) for fifteen minutes with 10 per cent. Fehling's solution on the hot water-bath. On then rinsing the fabric with water cuprous oxide will be found deposited on the stains. This test gives more satisfactory results than the methylene blue test (*supra*).³

Another dyestuff test for oxycellulose devised by Knaggs consists in treating the cotton with benzopurpurin, then rinsing it with acid, and finally with water until the red colour of ordinary cotton reappears. Any portions that have been converted in oxycellulose, however, will remain as blue-black spots.

Action of Organic Acids.—In experiments made by Dollfus the cotton was dipped in 2 per cent. solutions of oxalic, tartaric, and citric acids, dried and exposed to temperatures from 4° to 80° and finally 126° C., and it was found that eventually the cellulose was attacked. The intensity of the action increased with the concentration. In the case of a 4 per cent. solution the fibres were attacked more energetically by oxalic than by tartaric or citric acids, and the action was promoted by dry heat.

Absorption of Tannin.—There is a pronounced affinity be-

¹ "Bull. Soc. Ind., Rouen," 1883, xi. p. 233.

² "Chem. Centralbl.," 1901, i. p. 342.

³ "Bull. Soc. Ind. Mulhouse" (Kuhn, *loc. cit.*, p. 144).

tween gallotannic acid and the cotton fibre, and advantage is taken of this in the use of tannin as mordants in dyeing.

According to Gardner and Carter¹ cotton will absorb about 30 to 32 per cent. of gallotannic acid, but no gallic acid. The presence of a small proportion of a lower fatty acid, such as formic or acetic acid, increases the amount absorbed to 48 to 50 per cent.

The chemical combination, if such there be, between the cotton and the tannin is of a very loose description, since nearly the whole of the tannin may be removed by repeatedly washing the treated cotton with water.

Absorption of Gases.—Cotton has a great capacity for absorbing gases, and it is to this property that the greater effect of chlorine upon cotton than upon other vegetable fibres, such as flax, is to be attributed.

In the anhydrous condition cotton fibres are capable of absorbing more than 100 times their volume of ammonia gas.

Absorption of Dyestuffs.—Cotton has a much less affinity than animal fibres for dyestuffs, and relatively speaking there are only a few with which it may be dyed without the assistance of a mordant. Of the direct dyestuffs turmeric and annatto are typical of the natural vegetable colouring matters. Acid and azo coal-tar dyestuffs have little or no affinity for cotton, while, in general, any basic dyestuffs (e.g. methyl violet) which give a permanent colour only produce faint tints. The benzidine dyestuffs of the Congo group, however (so called from Congo-red, the first commercial dyestuff of the kind), and their derivatives the *benzopurpurins*, are known as direct or substantive cotton dyes, from the fact that they impart deep and fast colours to unmordanted cotton.

The nature of the attraction between the colouring matter and the fibre of the cotton remains an unsettled question, and numerous arguments have been brought forward in support of the opposing views of mechanical or physical absorption and of chemical combination.

Crum (loc. cit.) attributed the absorption to a mechanical

¹ "Journ. Soc. Dyers and Colourists," 1898, xiv. p. 143.

process, whereas Chevreul considered that, in some cases at all events, there was chemical combination. The fact that oxycellulose has a greater affinity than cellulose for basic dyestuffs (see p. 103), appears to support the chemical view, but on the other hand the change in chemical constitution may also merely have been accompanied by an increased mechanical surface attraction comparable with that exerted by animal charcoal in the decolorization of liquids.

Mordant colours include nearly all the natural vegetable dyestuffs, and the alizarine and other artificial dyestuffs. These are only retained by the fibre after it has been mordanted so as to contain a metallic oxide, which will combine with the dyestuff to form an insoluble compound which remains fixed. Thus the cotton may be dipped in gallotannic acid solution and then treated with stannic chloride, basic aluminium sulphate, etc., before the application of the dye. Or it may be treated with "Turkey-red oil," and then dipped in the solution of a metallic salt, so as to produce upon the fibre a metallic sulphoate which will combine with the dyestuff (e.g. alizarine red).

In the case of mineral colours, such as chrome yellow, Prussian blue, etc., the fibres are first treated with a chemical which will react with the colouring matter to form an insoluble compound within the fibres. From the fact that the resulting compound (e.g. lead chromate) may form crystals readily seen with the microscope, it would seem that in such cases the cellulose does not play a chemical part in the final retention of the dyestuff, even though there were a chemical combination between the metallic mordant and the substance of the fibres.

According to Kuhn¹ the more complete the dyeing process the greater the deposition of dyestuff along the lumen, but even in the best-dyed fibres, a considerable proportion of the colour is deposited, upon the outer surface.

It has been pointed out by de Mosenthal that a single fibre does not absorb colouring matter by capillary attraction, and

¹ *Loc. cit.*, p. 183

the dyestuff thus apparently rises between the fibres and passes into them by way of the pores and stomata.

Crum found that it was deposited within the central canal or lumen, but O'Neill¹ concluded that this was seldom the case, and that as a rule the whole cell-wall was coloured in a nearly uniform manner.

In the case of *unripe fibres* (see p. 84) the dyestuff is only deposited on the surface, and is readily removable by washing the yarn with water. Such fibres will appear white in a dyed fabric. Their absorptive capacity for dyestuffs may be improved by mercerization.

"Animalizing" of Cotton.—Silk, wool, and other animal fibres have a much greater affinity than cotton for dyestuffs, but by treatment with nitrogenous matter, such as casein, cotton approaches more nearly the animal fibres in its absorptive power.

Thus the cotton may be treated with a mixture of sodium stannate and milk, and subsequently dipped in a solution of alum.

In a more recent method devised by Vignon and Cassella, the cotton is subjected to the action of calcium chloride and ammonia at a temperature above 60° C. (Kuhn). Ammonia is absorbed, and the fibres are rendered capable of being dyed in an acid bath without a mordant.

Sized Cotton.—Prior to being woven into fabrics cotton yarns undergo a preparatory treatment known as "sizing" to render them softer, more pliable, and more adhesive. The earliest method employed probably consisted in dipping the yarns into flour paste and subsequently greasing them with tallow, but subsequently many other substances were employed. Those in use at the present day are classified by Bean and Scarisbrick² into the following groups (1) *Adhesive agents*—Flour, starch, dextrin, gum, etc. (2) *Substances giving weight and "body"*—China clay, magnesium sulphate, calcium sulphate, sodium sulphate, barium sulphate. (3) *Substances "softening" the size or*

¹ "Printing and Dyeing of Calico," n. p. 29.

² "Chemistry and Practice of Sizing," 1906, p. 8.

yarn: Tallow, oils, Japan wax, paraffin wax, glucose, soap. (4) *Substances softening and giving weight to size or yarn*: Magnesium chloride, calcium chloride, glycerin. (5) *Preservative agents*: Zinc chloride, carbolic acid, cresols, salicylic acid, thymol, etc.

Thomson¹ pointed out that the introduction of the deliquescent salts, magnesium chloride and calcium chloride, was followed by mildew and other signs of the action of mould-fungi. One of these, probably a *Penicillium*, produces rust-red stains, which have frequently been mistaken for iron-mould.

Thomson gives the following method of examining sized cotton ("Grey cloth"): About 10 to 20 grammes of the material are soaked in cold water, then pressed, treated first with 1 per cent. potassium hydroxide solution, then with 1 per cent. hydrochloric acid, washed thoroughly, and dried in the water-oven until constant in weight. The loss represents the moisture, the total amount of size, and the mineral matter natural to the fibre.

The total mineral matter is determined by igniting a weighed quantity of the material, and 1 per cent. is allowed as the quantity naturally present in the cloth. If china clay is present an addition of 10 per cent. to the weight of the ash is made to obtain the amount of moisture that would naturally be contained in the clay. The proportion of moisture normally present in the cloth itself is taken at 8 per cent.

The following table gives the results of analyses made by Thomson (loc. cit. p. 151) of six samples of grey cloth.—

Cloth.	Per cent	Per cent	Per cent	Per cent.	Per cent.	Per cent.
Fibre	47.29	53.02	60.75	70.84	80.51	81.78
Natural Moisture	4.11	4.61	5.28	6.16	7.12	7.11
Size Moisture	6.01	5.02	4.65	3.07	2.01	2.89
Starch, Oil, etc.	12.77	13.36	13.33	12.43	8.30	3.33
Mineral Matter	29.82	23.99	15.99	7.50	2.16	4.89
Mineral Matter—						
China Clay	Very large	15.08	11.43	Principally	Principally	Princip.
Magnesium Chloride	Moderate	2.42	Trace			
Calcium Chloride		43	2.50			
Zinc Chloride	Moderate	6.06	2.04	Small		
Sodium Chloride	Trace	Trace	Small			

¹ "Sizing of Cotton Goods," 1877, p. 164.

In Thomson's opinion cloth for shipment should be condemned if the following concomitant conditions are found: (1) Organic matter exceeding 13 per cent.; excess of moisture over 1 per cent., together with little or no zinc chloride. (2) Calcium chloride or magnesium chloride present with insufficient quantity of zinc chloride. (3) Mineral matter under 3 per cent., and starchy matter exceeding 15 per cent with more than 0.5 per cent. excess of moisture, and absence of strong antiseptic.

Polished Cotton.—Cotton thread with a glazed surface is prepared by sizing the material and polishing it in a brushing machine. The fibres of cotton treated in this way appear like those of ordinary cotton under the microscope, but the foreign matter may be observed. A commercial sample of polished cotton examined by us gave the following results: Moisture, 7.63; ash, 0.21; and "sizing," 1.86 per cent.

Destruction of Cotton by Mould-Fungi.—Raw cotton that is stored in a moist condition is liable to be attacked by mould-



FIG. 40.—Cotton Fibres Disintegrated by Mould.

fungi, and its fibres become weakened to such an extent as to be unfit for spinning. Bleached, unsized cotton resists the action of moulds, but sized cotton is readily attacked, especially when the size contains substances which attract moisture from the

air (magnesium chloride, etc.), and is deficient in antiseptic substances. Holle¹ studied the fungi that cause this deterioration. Cotton damaged by sea-water became discoloured in green and brown patches, and quite rotten, and colourless and brown mould-fungi were isolated from the material.

Waterproofed Cotton.—A material composed of cotton coated on both sides with caoutchouc is used for antiseptic dressings in the French army. The caoutchouc may be separated from the cotton by successive treatment with nitrobenzene and alcohol (95 per cent.). Two samples of this "batist" examined by Thal² gave the following analytical results :—

Batist.	Moisture.	Cotton Fabric	Total Sulphur.	Mineral Matter (as Nitrobenzene Residue)	Chlorine Nitrobenzene (Combined)	Caoutchouc (by Difference).
Single, per cent.	3.04	63.58	0.33	8.03	0.18	24.84
Double, per cent.	2.97	56.54	0.48	13.97	0.15	25.89

¹ "Chem. Zeit., " 1898, xxii, p. 824

² *Ibid.*, 1898, xxii, pp. 867, 880.

CHAPTER VI. MERCERIZED COTTON

Historical.—The term “mercerized” cotton not only describes what is practically a new fibre, but also commemorates the name of its inventor. It owes its origin to the investigations of Mercer¹ of the action of caustic alkalies upon cotton and other cellulose fibres, and the patent in which his discovery was described (Eng., Pat. 13,296, 1850) claimed that under the influence of caustic potash and soda (and of other chemical agents) the fibres were contracted and thickened, and rendered more absorptive of dyestuffs. It is noteworthy that no mention was made of the production of lustre, which was the outcome of a much later discovery.

For thirty years or more Mercer's discovery was little more than a failure from a commercial point of view. Specimens of fabrics woven of the treated cotton were shown at the International Exhibition of 1851, but owing to the high price of caustic alkali at that time, and the fact that the advantages of the treatment appeared insufficient to justify the initial cost, the process soon fell into a commercial decline.

Hence by the year 1880 mercerized cotton was practically unknown, notwithstanding the fact that caustic soda could then be obtained at a relatively low price.

The revival of the industry appears to date from the patent taken out in 1883 by Garnier and Depouilly (Eng. Pat. 28,696, 1883), who showed that by treating a fabric consisting of mixed vegetable and animal fibres with a solution of caustic alkali the former were contracted while the latter remained unaltered, with

¹ Born 1791; died 1866.

the result that a crêpe, or, as they termed it, "crumpled cloth," was produced.

The production of lustre was at that time regarded as a drawback, and mechanical means were adopted to prevent its appearance; and it is not until 1889 that we find in a patent, taken out by Lowe (Eng. Pat. 20,314, 1889) a claim for the production of a more glossy material.

The novelty in this patent is the stretching of the fibres during the treatment with the caustic alkali, the result being that excessive shrinkage is prevented and the fibres become lustrous.

From that date onwards patents have followed each other in rapid succession, and the conditions for obtaining the highest degree of lustre or the best absorption of dyestuffs have been thoroughly investigated.

Outline of the Process.—For the production of a pronounced lustre upon the fibres, which is now the primary aim of mercerization, the nature of the yarn is an important factor, some cottons being naturally much more glossy than others. Thus the silky, long-shaped Egyptian and Sea Island cottons are largely employed, and their natural glossiness is increased by combing and "gassing" to remove the minute surface hairs.

The twisted cotton is then steeped and treated with a bleaching agent, such as dilute caustic soda solution and sodium hypochlorite, though some authorities favour the use of bleaching after mercerization.

The bleached hanks are washed, stretched on rollers, and carried through the mercerizing solution, the strength and temperature of which are carefully regulated.

Caustic potash imparts slightly more lustre, and, according to Beltzer, sodium peroxide is still more effective though its use is attended with risk of injury to the fibre. An addition of carbon bisulphide to the soda bath has also been employed as a means of increasing the lustre, but the duration of the immersion of the cotton has to be exactly regulated to obtain sufficient action without weakening the fibres. With regard to the tension it is usual to stretch the cotton yarns before the bath,

though in some methods the tension is applied after the action of the soda; and in others, again, the cotton is stretched during the mercerization and the tension increased during the subsequent washing. In some factories a heavy roller is placed upon the upper roller carrying the cotton, and an increase of lustre thus imparted to the fibres.

Most of the later patents deal with improvements in the machinery for the immersion and stretching of the cotton, or with modifications of the bleaching or mercerizing solutions. In one of these modifications claim is made for the use of reagents such as sodium silicate or glycerin to prevent excessive shrinkage of the fibres in the alkali bath. Several attempts have been made to effect combined bleaching and mercerization in the same bath, but these do not appear to have been entirely successful, owing to the difference in the strengths of the alkali solution required for the two processes.

After the treatment with alkali the cotton yarns are passed between rollers to express the excess of caustic soda solution, and are finally rinsed with warm water to complete the chemical part of the process, and dried. When a very high degree of lustre is desired the mercerized cotton is calendered.

Calender finish.—The calender designed in 1865 by Appleby was one of the earliest machines employed to impart a silken appearance to cotton goods by means of rollers engraved with fine lines. In *Schreiner's process* (Eng. Pat., 7637, 1895) the cloth is subjected to a pressure up to 300 atmospheres between rollers, one of which is covered with finely engraved lines up to 600 per square inch. The effect of this is to produce an immense number of minute planes which reflect the light, and render the cloth lustrous. The use of hot rollers makes the silk-like effect more permanent, but even then washing destroys much of the lustre. The fibres of fabrics are not infrequently injured by hot calendering, especially when they have already been weakened by faulty bleaching.

Structural Alteration of the Fibres.—The immediate effect of immersing cotton fibres in a solution of caustic alkali is to cause shrinkage of the fibres, the amount of which depends

upon the strength of the solution, while at the same time the characteristic twists of the fibre are straightened out, and the fibre becomes more tubular, though without becoming lustrous.

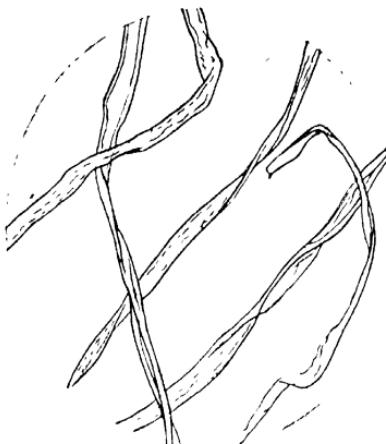


FIG. 41.—Cotton Fibres before Mercerization

Hübner and Pope¹ have studied under the microscope the action of caustic soda solutions of different strength upon loose fibres, and give the following summary of their observations:—

Strength of Soda Solution. ²	Effect
Up to 15° Tw.	No apparent change.
From 16 to 18° Tw.	Slight but incomplete untwisting.
At 20° Tw.	Initial untwisting followed by slow uncoiling of the twist, but fibre not quite unrolled.
At 26° Tw.	Rapid and slow uncoiling become one, lasting five seconds.
At 35° Tw.	Untwisting followed by swelling.
At 40° Tw.	Untwisting and swelling take place together.
At 60 to 80° Tw.	Swelling precedes untwisting.

¹ "J. Soc. Chem. Ind." 1904, xxii. p. 404.

² Degrees Twaddell correspond approximately to the percentage strengths of the alkali solutions.

Shrinkage.—The amount of shrinkage caused by the different strengths was found to increase steadily up to 18 to 20° Tw. At the latter point a sudden increase in shrinkage took place.

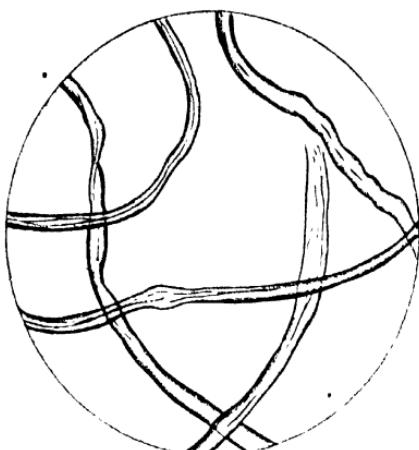


FIG. 42.—Cotton Fibres after one hour's Immersion in Strong NaOH Solution.

The greatest shrinkage was observed with a solution of about 45° Tw., and from thence onwards to 80° Tw. showed a uniform decrease.

Production of Lustre.—When stretched fibres were mercerized the twisted ribbon-like ones were seen to be straightened into nearly circular rods carrying a series of spiral elevations, the sides of which reflected the light and thus produced the lustrous effect.

In the yarn the fibres are held so closely together that many cannot untwist freely, and hence fibres with the characteristic twists are common in mercerized fabrics. When single fibres are immersed in the alkali solution, however, and subsequently stretched, they are straightened and show the smooth and rounded ridges described by Hubner and Pope.

It has also been shown by the same observers that the reagents which cause rapid untwisting, great swelling, and considerable shrinkage are those that impart lustre to the stretched

yarn, and that in the absence of one or more of these effects little or no lustre results.

Thus lustre is produced by caustic alkalies and by nitric acid, whereas hydrochloric acid, which causes rapid untwisting

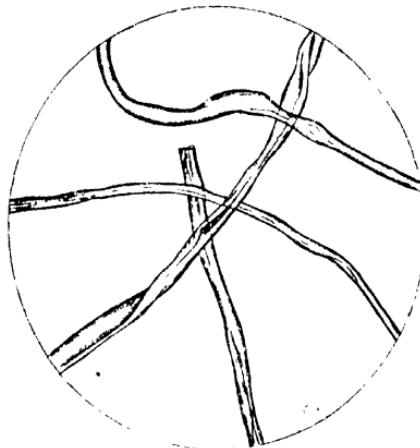


FIG. 43.—Cotton Mercerized and Stretched, showing Incomplete Mercerization.

but only slight swelling and shrinkage, gives but little lustre; and barium mercuric iodide solution, which produces much swelling and shrinkage, but does not untwist the fibre, also imparts very little lustre.

Affinity for Dyestuffs.—According to the results of the systematic experiments of Hübner and Pope (*loc. cit.*) the affinity of cotton for direct dyestuffs is increased by treatment with caustic soda solution of 100° Tw., and the amount of increase is approximately proportional to the strength of the solution up to about 18° Tw. The maximum effect is reached with solutions of 60 to 70° Tw., and from that point onwards there is a decrease, a solution of 80° Tw., for instance, having less effect than one of 70° Tw. Cold solutions have a greater effect in increasing the affinity than hot solutions, a cold solution of 30° Tw., for instance, having the same effect as one of 50° Tw. at a temperature of 80° C. Other reagents, e.g. barium mercuric iodide, potassium iodide, zinc chloride, and nitric acid

also cause increased affinity for direct dyestuffs with the increase in the concentration of their solutions.

Chemical Change in Mercerization.—It is commonly accepted that the cellulose of the cotton first enters into combination with the alkali to form an alkali-cellulose, the composition of which largely depends upon the concentration of the caustic soda solution (see p. 98). During the rinsing with water in the final stage of the mercerizing process this alkali-cellulose is transformed into a cellulose hydrate having the composition, $2C_6H_{10}O_5 + H_2O$.

From the experiments of Hubner and Teltscher, however (see p. 99), it would appear that soda-celluloses of definite composition are not formed in the mercerizing process.

Schwalbe¹ takes the water of hydration as the difference between that expelled at 100° to 105° C. (hygroscopic moisture), and that expelled at the temperature of boiling toluene. He obtains the total amount of water by distilling the hydrated cellulose with toluene, and absorbing the moisture in a weighed calcium chloride tube.

The degree of hydration is indicated by treating the mercerized cotton with a solution of iodine and zinc chloride and noting the speed with which the colour is removed on washing with water (*vide infra*).

Fraenkel and Friedlaender¹ conclude that the production of lustre is due to the removal of the outer cuticle of the fibre, partly by a chemical and partly by a physical process. In their opinion the cuticle is partially dissolved by the alkali solution, but the greater portion is removed by the swelling of the fibre assisted by the applied tension. The swelling of the fibre may probably be attributed to a change in volume due to the conversion of the cellulose into alkali-cellulose.

Effect upon the Strength of the Fibre.—Mercerization properly carried out increases the strength of the fibre of the cotton. Thus in the three experiments described by Fraenkel and Friedlander (*loc. cit.*), the strength of the original yarns were equivalent to 360, 356, and 360 grammes, while after mer-

¹ "Ber. d. d. chem. Ges." 1907, xl. p. 4523.

² "J. Soc. Chem. Ind." 1898, xvi. p. 839.

cerization with caustic soda solution of 35° Bé., the strength had increased to 530, 570, and 559 grammes respectively.

Hubner and Pope¹ criticize the methods of determining the mean strength of a yarn, and point out that however uniform the size and the twist of the spun threads may be, it is unlikely that some should not break before data have been obtained that would give the mean tensile strength of the yarn.

In their investigations they take the average breaking strain of a large number of individual threads in Schopper's tearing machine, after exposure for twenty-four hours to an atmosphere with a hygrometer reading of 55 to 65, and they show that the mean results thus obtained are probably accurate within 0·45 per cent.

In this way the following comparative results (among others) were obtained :—

Treatment	Raw Yarn	With 15 per cent. Na_2CO_3 Solution	With NaOH Solution, 1 day	With KI Solution, 1 day	With BaI_2 Solution, 1 day.	With $\text{BaI}_2 \cdot \text{HgI}_2$ Solution, 1 day.
Average tensile strength	378	419·7	530·9	431·6	433·4	534·3
Length in cm.	66·0	65·6	45·2	65·0	65·2	52·3

Measurement of Shrinkage.—The shrinkage under the influence of the different reagents was measured by Hubner and Pope by hanging the cotton from a hook with a weight of 25 grammes at the other end, and measuring the length by means of a millimetre scale.

They show that when once a yarn has been shrunk by mercerization and then washed and dried, it cannot then be re-stretched to its original length. Thus in the above examples the "yarn of 66 cm. was shrunk to 45·2 cm. by the action of caustic soda, and when subsequently washed and dried broke at a length of 58 cm. On the other hand, cotton kept stretched to its full length during mercerization does not subsequently shrink.

¹ "J. Soc. Chem. Ind.," 1903, xxii. p. 70.

Reactions and Tests for Mercerized Cotton.—It is not always easy to tell by means of the microscope whether the cotton in a fabric has been mercerised or not, for during the mercerisation the inner fibres in the hank are relatively protected against the action of the caustic soda, and many of them will still retain the characteristic twisted form of the untreated cotton (see Fig. 43).

It is therefore essential to supplement a microscopical examination by one or more chemical tests.

Iodine in Potassium Iodide Solution.—It has been found by Hübner¹ that on immersing small quantities of ordinary and mercerized cotton for a few seconds in a solution of 20 grms. of iodine in a 100 c.c. of a saturated solution of potassium iodide, and washing them with water, the former becomes very pale brown whilst the latter remains black. After long-continued washing the ordinary cotton becomes colourless and the mercerized cotton a blue-black, which only fades very slowly.

By using an N/100 solution of iodine and exposing the cotton to the air, ordinary cotton becomes nearly colourless in a very short time, while mercerized cotton shows a gradation of colour corresponding to the strength of caustic soda used in the mercerisation. If the samples are dipped in a strong solution of iodine (30 grms. in 100 c.c. of saturated KI solution) and then washed with a 2 per cent. aqueous solution of potassium iodide, the iodine is removed more slowly than by treatment with water. The untreated cotton then becomes light brown, while the mercerized cotton remains a brownish-black.

Cotton mercerised without tension has a greater absorptive power for iodine than that stretched during the treatment with alkali.

Zinc Chloride and Iodine.—It has been shown by Schwalbe that the greater the degree of hydration of the cotton the more firmly is the iodine retained by the material when treated with a solution of iodine and zinc chloride.

The most suitable conditions for the test have been worked out by Hübner (loc. cit.), who finds that this reagent is still better than iodine solution for determining what strength of caustic

¹ "J. Soc. Chem. Ind." 1908, xxvi. p. 105.

soda was used in the mercerization, and hence whether the process had been properly carried out.

The blue-black colour given by this reagent with ordinary cotton is much more rapidly removed by washing than the colour obtained with mercerized cotton, though the latter is less stable than that given by the strong iodine reagent.

The most distinctive colorations are produced by a solution of 280 grms. of zinc chloride in 300 c.c. of water, to 100 c.c. of which are added 20 drops of a solution of 1 grm. of iodine and 20 grms. of potassium iodide in 100 c.c. of water.

The following reactions were obtained on treating cotton (mercerized with successively increasing strengths of caustic soda) with different proportions of the iodine solution added to 100 c.c. of the zinc chloride solution. In each case the cotton was left until the maximum coloration was obtained.

Strength of Caustic Soda.	I. 20 Drops of Iodine Solution.	II. 10 Drops of Iodine Solution	III. 5 Drops of Iodine Solution.
Tw	—	—	—
0	Slight red tint	Remains white	Colourless
10	Faint chocolate-red	Very faint brown tint	Colourless
20	Dark bluish-chocolate	Darker, more choc- olate	Colourless
23	Darker, more bluish	More bluish, stronger	Colourless
26	Much darker, bluish- chocolate	Much darker and bluer	Colourless
30	Very dark reddish- navy blue	Darker, reddish-blue	Faint blue tint
40	Black	Much darker than 30	Bluer
50	Black	Darker than 40	Much darker blue
60	Black	Darker than 40	Slightly lighter than 50
70	Black	Darker than 40	Lighter than 50 or 60

Hence solutions 1 and 2 will show whether cotton has been treated with solutions of caustic soda of 10° to 30° Tw., while solution 3 will indicate the use of solutions of 30° to 60° Tw.

Where the lower strengths (i.e. below 50° Tw.) have been employed, the proper mercerizing effect will not have been produced.

A further test is supplied by the rates at which the colours fade on exposure to the air, the darkest being the most persistent.

In examining woven fabrics the material should be dipped in water and pressed between filter-paper before treatment with the reagent. The test is not interfered with by preliminary removal of dyestuffs.

Cotton mercerized with other reagents than caustic soda gives a blue colouration with the reagent, but where hydrochloric acid, mercuric iodide solution or potassium iodide solution have been used as the mercerizing agent, a stronger solution (380 grms. of zinc chloride in 300 c.c.) is required.

Aluminium Chloride and Iodine.—A solution of 46·7 grms. of aluminium chloride containing 15 to 20 drops of iodine solution per 100 c.c. gives a dark chocolate-brown coloration with mercerized cotton after an hour's immersion, while ordinary cotton remains practically colourless (Hubner).

Dyestuff Tests.—Several tests for mercerized cotton have been based upon the fact that the process increases the affinity of cotton for substantive dyestuffs.

Knecht¹ finds that ordinary cotton dyed with benzopurpurin becomes blue on the addition of hydrochloric acid, while mercerized cotton is changed to reddish-violet. By adding titanous chloride solution to the liquids from a burette, ordinary cotton appears indigo blue and mercerized cotton red at the stage immediately before decolorisation, provided caustic soda stronger than 30° Tw. had been used without tension, or 35° Tw. with tension. Cotton that has been treated with nitric acid of 83° Tw. also gives this reaction.

The percentage of dyestuff absorbed by the cotton increases steadily with the strength of the alkali solution. Thus in comparative experiments ordinary cotton absorbed 1·77 per cent. of benzopurpurin; cotton mercerized with caustic soda of 20° Tw. 2·39 per cent.; with 40° Tw., 3·15 per cent.; with 50° Tw., 3·38 per cent.; with 60° Tw., 3·56 per cent.; and with 70° Tw. 3·66 per cent.

¹ "J. Soc. Dyers and Col." 1908, xxiv. p. 67.

Knaggs¹ finds that the reduction with titanous chloride or stannous chloride in Knecht's qualitative test for mercerized cotton is unnecessary, and that it is sufficient to add hydrochloric acid drop by drop to the dilute dye bath in which the specimens of cotton are lying. At the point at which the ordinary cotton is just changed to blue, the mercerized cotton will remain bright red. This is not due to residual alkali in the latter; for on adding acid to the mercerized material until it too becomes blue, and again immersing it in the dyestuff solution, the red colour again appears.

¹ "J. Soc. Dyers and Col.," 1908, xxiv. p. 112.

CHAPTER VII.

ARTIFICIAL SILKS.

Historical.—The notion of producing by mechanical means fine threads which would possess the lustre of natural silk is by no means recent. As far back as 1734 it was suggested by the French naturalist Réaumur, that since silk was what he described as a naturally hardened gum it should be possible to produce similar filaments by forcing a varnish, such as that used by the Chinese, through minute openings, and drying the threads thus obtained.

But this idea was not followed up, and it was not until after the lapse of 120 years that any practical attempts were made in this direction. Then, in 1855, Andemars of Stockholm took out a patent (Eng. Pat., 283, 1855), in which nitrated cellulose prepared from the bast fibres of the mulberry tree was dissolved in a mixture of alcohol and ether, and the solution incorporated with a solution of india rubber. A steel point was dipped into the viscid liquid, and the threads adhering to it were drawn out into fine filaments by means of a winding machine.

This invention, which may be regarded as the parent of the processes of the present day, did not achieve commercial success, and no further attempts to manufacture an artificial silk appear to have been made until 1883, in which year, J. W. Swan (Eng. Pat. 5978, 1883) claimed a process of preparing threads from a solution of nitro-cellulose passed through minute orifices and denitrated by means of ammonium sulphide or other deoxidizing agent. Although primarily intended for the manufacture of filaments for incandescent burners, the threads described in the patent were used experimentally in the weaving of textiles.

The real beginning of the industry, however, is due to Chardonnet, who took out his first patent in this country in 1885 (Eng. Pat. No. 6045, 1885), and to carry out whose process a company was formed and works opened at Besançon. Similar processes were patented by Du Vivier (Eng. Pat. No. 2570-1, 1889) and by Lehner (Eng. Pat. No. 11,094, 1890), the basis of all three preparations being a solution of nitrocellulose, which was forced through minute openings, the threads being subsequently freed from the solvents.

The problem more or less successfully solved in the processes that have been worked on a commercial scale is, in the main, a mechanical one. The difference in lustre between silk and cotton is due not to a difference in chemical composition, but to a different physical structure; and, as was pointed out in the description of mercerized cotton, the surface of the cotton fibre may be so altered by the action of alkali and of tension that it reflects the light, or, in other words, becomes lustrous. In like manner a solution of cellulose or its compounds, passed through minute orifices, produces filaments with a lustrous surface and of a degree of fineness that approaches much more closely than mercerized cotton to the fibres of true silk. The term "lustracellulose" was suggested by Cross and Bevan¹ as a more appropriate description of these products than the misleading term "artificial silk".

In addition to nitrocellulose, alone or in admixture with other substances, solutions of cellulose or of other compounds of cellulose have been employed. Thus in Pauly's process (Eng. Pat. 28,631, 1897) a solution of cellulose in an ammoniacal solution of cupric oxide (cuprammonium) is used, while Stearn (Eng. Pat. 1020, 1898) claimed the use of a solution of viscose (q.v.). Solutions of cellulose in zinc chloride solution; of cellulose hydrate in caustic alkali solutions; and of cellulose acetates and formates have also been made the basis of lustra-cellulose preparations; but products made from nitrocellulose, from cellulose in cuprammonium, or from viscose, are the only ones that have, as yet, attained much commercial importance.

¹ "J. Soc. Chem. Ind.," 1896, p. 317.

Preparations with a basis of animal material have been made on a small scale, but have not met with the success of the lustr celluloses. The first process of this kind is described in Millar's patent for "Vanduara silk" (Eng Pat., 15,522, 1894), in which claim is made for the use of a solution of gelatin, the threads being subsequently rendered insoluble. Another process belonging to this class is that of Todtenhaupt (Eng Pat., 25,296, 1904), in which the threads are prepared from an alkaline solution of casein.

Artificial silks are made on a manufacturing scale by the Chardonnet process at Besançon in France, by the Guido Furst Kunstseiden Werke in Stettin (viscose silk); at Frankfurt, Elberfeld, and in Belgium (Linkmeyer and Thiele silk); and on a smaller scale in this country and the United States. They are extensively used in the manufacture of ribbons, tapestry and other fabrics in which strength is not the primary consideration.

According to Dreaper¹ the production of raw silk throughout the world in 1904 amounted to 21,145,000 kilos, while the estimated output of artificial silk in 1906 was 2,400,000 kilos. All the large companies in Germany, France, and Belgium engaged in the manufacture showed substantial profits in 1906.

Dreaper gives the price of crude real silk at 45 to 48 francs per kilo, or, taking into account the loss during the "boiling off" process, at 66 to 70 francs, while Thiele silk fetches at least 28 francs per kilo and Linkmeyer silk 22 to 26 francs per kilo. In 1903 Chardonnet silk had risen in value to 40 francs per kilo.

Outline of Processes.—*Chardonnet's Process.*—Nitrocellulose, prepared from cotton or wood pulp, is dissolved under pressure in a mixture of ether and alcohol, and the viscous solution forced through small openings ("silk worms") $\frac{1}{100}$ mm. in diameter. The filaments formerly received under water are now spun dry, the solvent evaporating and leaving the nitrated cellulose. Three, four or more fibres are spun together and the threads

¹ "J. Soc. Dyers and Colourists," 1908, xxii. p. 1.

denitrited by immersion in a 5 to 20 per cent. solution of ammonium hydrosulphide, and finally washed, dried and dyed to any colour desired.

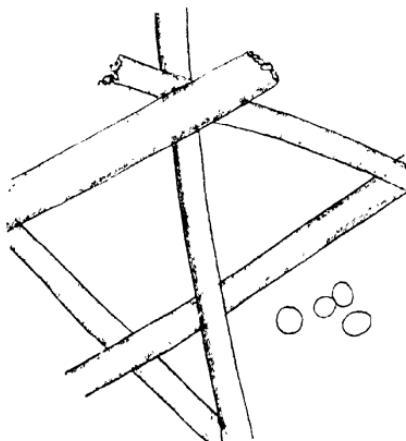


FIG. 44.—Chardonnet Artificial Silk, showing Cross-sections

Du Vivier's Process.—The solution of nitrated cellulose in glacial acetic acid is mixed with a solution of fish glue in acetic acid and of gutta-percha in carbon bisulphide. According to Süvern this product, known as *Soie de France*, is no longer on the market.

Lehner's Process (Eng. Pat. 11,094, 1890).—A solution of nitrocellulose is mixed with a solution of silk waste, and the filaments passing through small glass tubes precipitated by means of water.

Pauly's Process (cuprammonium silk) (Eng. Pat. 28631, 1897).—A solution of cellulose in an ammoniacal solution of cupric oxide is forced through fine jets on to rollers revolving in acetic acid.

Stearn's Process (viscose silk) (Eng. Pat. 1020, 1898).—Cellulose is treated with strong alkali and carbon bisulphide, the resulting "viscose" dissolved in water, and the solution filtered and forced through jets into a solution of ammonium chloride, which reprecipitates the "viscose".

Dreaper and Thomson's Process (Eng. Pat. 17,901, 1898).—A solution of cellulose in zinc chloride solution is forced through jets into alcohol or acetone, which reprecipitates the cellulose.

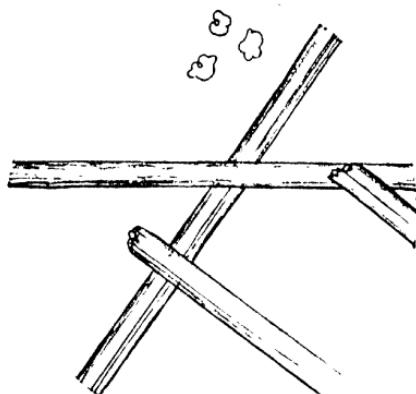


FIG. 45.—Viscose Artificial Silk

Millar's Gelatin Vanduara Silk.—A viscous solution of gelatin is passed through fine openings on to a rapidly travelling endless band, the dried filaments twisted together, and the threads exposed to formaldehyde vapour or other agent rendering the gelatin insoluble in water. It can be dyed readily with aniline dyestuffs.

Linkmeyer's process (Eng. Pats., 4755, 4756, 1905).—The cuprammonium solution of cellulose is coagulated by the addition of a solution of caustic alkali, the threads remaining blue and transparent. Normann¹ found that this is due to a formation of a copper-alkali-cellulose, $C_{12}H_{20}O_{10}CuO$. The compound is dissociated by water, copper hydroxide being deposited in the thread. When the copper is removed by treatment with dilute acids, the decolorised threads remain perfectly transparent.

Thiele's process (Eng. Pat., 8083, 1902).—A highly concentrated solution of cellulose in cuprammonium solution is passed through wide openings into a vessel containing a substance (e.g. ether)

¹ "Chem. Zeit," 1906, xxx. p. 584.

which slowly precipitates the cellulose. The threads are then drawn out to extreme fineness, e.g. by means of glass roller revolving in acid.

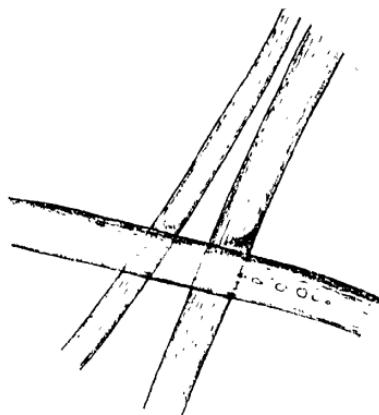


FIG. 46.—Belgian (Cuprammonium) Artificial Silk

Strehlenert's process (Eng. Pat., 22,540, 1896).—In order to minimise the reduction in strength of collodion silk when wet, an addition of an aldehyde such as formaldehyde, etc., is made to the solvent in which the nitrated cotton is dissolved.

Todtenhaupt's process (Eng. Pat., 25,296, 1901).—The threads are formed from a solution of casein in an alkali fluid, passed through minute openings into an acid bath.

Properties of Artificial Silk.—Compared with true silk the different kinds of artificial silk feel harsher to the touch, and lack the elasticity of the natural product. They are quite as brilliant in appearance, and in fact complaint has been made of over brilliance in the case of some of them. Thus gelatin silk has a scintillating effect which is not found on genuine or wild silk. In some of the more recent preparations, e.g. Thiele's silk, steps have been taken to prevent this excess of lustre.

Size of Filaments.—The average thickness of the filaments of different kinds of artificial silk was found by Massot¹ to be as

¹ "Leipzig Monats. f. Textile-Ind." 1902, pp. 760, 832; 1905, p. 131.

follows: Chardonnet silk, $28.8\ \mu$; Lehner's silk, $35.4\ \mu$; cuprammonium silk (Glanzstoff), $31.4\ \mu$; and viscose silk, $30.51\ \mu$. Genuine silk ranges from 8 to $24\ \mu$, the average thickness being $15\ \mu$ (Hohnel).

According to Cross and Bevan¹ viscose silk filaments are now made in sizes of 5 to 8 deniers, the fibres of raw silk averaging 2.75 denier and those of "boiled off" silk 2.0 deniers, whilst the artificial silk threads spun from the filament measure 110 to 130 deniers.

In Dreaper's opinion² threads of this size are unsuitable for silk dresses, for which silk of 10 deniers is used, and still less suitable for silk gauze, which requires smaller sizes. If fewer filaments are employed to reduce the 110 denier size the thread becomes unworkable.

By Thiele's process "silk" of 10 denier and less is produced, and Dreaper asserts the possibility of manufacturing a thread of 20 deniers made up of at least 80 filaments, the elasticity thus gained enabling the material to be used in the warp in weaving.

The fibres of artificial silk swell up when immersed in water, whereas the fibres of true silk and tussah silk remain practically the same. Thus Massot found Chardonnet silk to increase in thickness by 61 to 62 per cent. in an hour, and viscose silk by about 45 per cent. in ten minutes.

Strength and Elasticity.—Silbermann³ gives the relative strength of Chardonnet silk, ordinary silk, and tussah silk, as 17, 38 and 48, while Vivier silk was 9 on the same scale. Compared with genuine Italian silk Lehner's silk was as 68, 100.

Strehlenert⁴ determined the absolute strength of different varieties of silk and artificial silk in the dry and moist condition, and obtained the following results expressed in kilos. per square metre—

¹ "Researches on Cellulose," p. 1906.

² "J. Soc. Dyers and Colourists," 1907, xxiii, p. 11.

³ "Die Seide," p. 1897, p. 143.

⁴ "Chem. Zeit," 1901, p. 1100.

	Dry	Wet
Chinese raw silk	53.2	46.7
French ,	50.4	40.9
French silk dyed and weighted	7.9	6.3
Chardonnet silk undyed	14.7	1.7
Lehner's silk	17.7	4.3
Strehlenert's silk	15.9	3.6
Cuprammonium silk (Glanzstoff)	19.1	3.2
Viscose silk	11.4	3.5

Chardonnet silk loses about 8 per cent. in strength in the process of denitration, probably through the formation of oxy-cellulose (see p. 92). The loss of strength on wetting this and other cellulose silks may be due to the formation of cellulose hydrates.

In Thiele's process it is claimed that the strength of the thread is only about 20 per cent. less than that of genuine silk, and that the loss of strength on wetting the substance is relatively small.

The strength of gelatin "Vanduara" silk is inferior in the dry state to that of the nitro-cellulose products, and is enormously reduced by wetting.

Chardonnet¹ found the elasticity of his artificial silk to be about 15 to 20 per cent. less than that of natural silk.

According to Silbermann (loc. cit.) the elasticity of true silk is 17.2 per cent.; that of tussah silk 18 per cent.; Chardonnet silk, 11.6 per cent.; and Vivier silk, 9.6 per cent.

Thiele claims that his product is practically equal in elasticity to genuine silk.

Covering Power.—One of the principal points in which artificial silks are inferior to the natural product is in their covering power, the filaments of true silk forming a more open thread, which has thus a thicker appearance than an artificial thread of the same weight. In the most recent products of Thiele's process, however, in which a great number of filaments is spun into a fine thread, this drawback is said to have been very greatly reduced.

Specific Gravity.—The specific gravity of the cellulose silks

¹ "Comptes Rend.," 1889, cviii. p. 962.

is considerably higher than that of genuine silk. Hassack¹ gives the following figures: Italian raw silk, 1.36; Chardonnet silk, 1.52; Lehner's silk, 1.51; cellulose silk, 1.50; and gelatin (Vanduara) silk, 1.37.

Fruchot² gives the specific gravity of silk as 1.357 to 1.37 and that of lustra-cellulose as 1.490.

Water.—Artificial silks contain about 2 per cent. more moisture than natural silk.

Süvern³ obtained the following results: China raw silk, 7.97; tussah silk, 8.26; Chardonnet silk, 10.37 and 11.17; Lehner's silk, 10.71; cuprammonium silk (Glanzstoff), 10.04; viscose silk, 11.44; and Vanduara (gelatin) silk, 13.02 per cent.

Hassack (loc. cit.) gives very similar figures: " Indian raw silk, 8.71; Chardonnet silk, 11.11; Lehner's silk, 10.45; cuprammonium silk (Glanzstoff), 9.20; and gelatin silk, 13.98.

After being dried at 100° to 115° C. and exposed to a moist atmosphere, these samples absorbed the following amounts of water: Italian silk, 20.11; Chardonnet silk, 27.46; Lehner's silk, 26.45; cuprammonium silk, 23.08; and gelatin silk, 45.56 per cent.

Artificial silk made by the nitration process (Chardonnet's Vivier's and Lehner's silk) contains only about 3 per cent. of moisture prior to the denitration.

Specimens of artificial silk recently examined by us gave the following results.—

Artificial Silk	Moisture (Loss at 100 C.).	Moisture Absorbed in Damp Atmosphere by Silk Dried at 100° C.	
		Per cent	Per cent
Chardonnet Silk (French)	12.68	42.7	
Viscose Silk (Fürst Gundo's)	9.42	33.9	
Cuprammonium Silk (Lambauer's "Soie de Hat")	11.60	23.79	

¹ "Oest. Chem. Zeit.," 1900, p. 269.

² "Ann. de Chim. Anal.," 1898.

³ "Die künstliche Seide"

Microscopical Appearance.—The difference between true and artificial silk, is, as a rule, very obvious under the microscope. The appearance of cross-sections, in particular, is often very characteristic (see Figs. 44-46).

Appearance in Polarised Light.—The Chardonnet silk mentioned above could be distinguished from the viscose and cuprammonium silk by its appearance in polarised light under the microscope. The two latter were of a uniform bluish-gray colour, whilst the collodion silk was bright blue (cf. Nitration of Cellulose, p. 101).

Reactions and Chemical Tests.—The lustra-celluloses, which, in this country, are the artificial silks ordinarily met with, are insoluble in a strong solution of potassium hydroxide, while ordinary silk dissolves.

Alkaline Copper Glycerin Solution dissolves silk and gelatin "silk," but not the cellulose silks.

Cuprammonium Solution (*Schweitzer's reagent*) dissolves both the cellulose products and natural silk. In the case of the former a white precipitate of cellulose is obtained on dilution with water.

Mineral Matter.—Ordinary silk emits an odour of burnt horn when ignited, and leaves an ash which requires long heating to become white.

Artificial silks examined by Schwalbe yielded 1 to 1·6 per cent. of ash, while Pauly's (cuprammonium) silk gave less than 0·1 per cent.

The specimens examined by the authors gave the following results: Chardonnet silk, 2·23 per cent.; Furst Guido's viscose silk, 0·28 per cent.; and *Soie de Hal* (cuprammonium) silk, 0·18 per cent. of ash. The viscose silk contained 0·17 per cent., and the other two slight traces of phosphoric acid (as P_2O_5).

⁴ A sample of Stearn's viscose silk examined by Sivern and Mach yielded 0·46 per cent. of an alkaline ash.

Nitrogen.—Only the collodion silks contain an appreciable quantity of nitrogen, and that is usually less than 0·2 per cent., whereas ordinary silk contains about 17 per cent. The traces of nitrocellulose still left in these silks, however, may readily be

detected by the diphenylamine test, and in this way Chardonnet's and Lehner's silk may be distinguished from viscose and cuprammonium silks.

In applying the test a small portion of the sample is dissolved in concentrated sulphuric acid to which has been added a trace of diphenylamine.

The collodion silks give an immediate bright blue coloration, while the other cellulose silks give only a slight yellow coloration.

Brucine hydrochloride may be used instead of diphenylamine, a blood-red coloration then being given by the collodion silks, while viscose and cuprammonium silk colour the sulphuric acid yellow.

Fehling's Solution.—During the nitration process in the manufacture of collodion silks a small amount of oxycellulose is produced (see p. 99), and Schwalbe has based a method of distinguishing between collodion and other cellulose silks on the fact that this oxycellulose causes reduction of Fehling's solution. If 0·2 grm. of the artificial silk be heated with 2 c.c. of Fehling's solution, a green colour is obtained with Chardonnet's or Lehner's silk, while in the case of viscose or cuprammonium silk the liquid remains blue.

Iodine and Zinc Chloride.—Schwalbe recommends the use of a solution of 20 grms. of zinc chloride, 2 grms. of potassium iodide, and 0·1 grm. of iodine in 15 c.c. of water, as a reagent for distinguishing between viscose silk and Pauly's (cuprammonium silk). When equal quantities of each are treated with the reagent and then washed with water, the viscose silk retains its (blue-green) colour for a considerable time, whereas the Pauly (cuprammonium) silk soon loses its (brown) colour.

*We are unable to confirm the value of this test in the case of other kinds of silk. Thus Chardonnet silk, Fürst Guido (viscose) silk, and *Soie à la Hal* (cuprammonium silk) all gave deep blue or violet colorations in the reaction, though one was rather more stable than the others.

¹ "Farber Zeit.," 1907, xvi, p. 273

CHAPTER VIII.

LINEN.

Source.—Linen is manufactured from the inner bark or *bast* fibres of the flax plant, *Linum usitatissimum*, which is extensively cultivated in all northern European countries, in Italy and on the coasts of the Mediterranean, in North America and in India.

As in the case of the cotton plant the number of species of flax described by botanists is very large, upwards of 100 having been tabulated, but of these only the common blue-flowered flax has attained any degree of commercial importance. The differences between many of the so-called species is so slight that it is questionable whether it is justifiable to assign them a separate position.

In any case, very few species have undergone systematic cultivation. The most ancient of these is probably the narrow-leaved flax, *L. angustifolium*, which is grown on the Mediterranean coasts. This is said to have been the source of the flax found in the lake dwellings of Switzerland, and used at a later period by the inhabitants of ancient Italy.

The flax of the Bible, that in use in Egypt and Assyria, was the ordinary flax of the present day.

In addition to these species mention may also be made of *L. crepitans* (Greek or spring flax), a smaller plant than common flax, cultivated to some extent in Russia and Austria; of *L. perenne* (perennial flax) grown in Austria and experimentally cultivated in India; and of *L. catharticum* (purging flax), also cultivated in Austria.

There is also another perennial species, *L. lewisii*, which is

used by the North American Indians for making the twisted cords for their fishing nets, etc.¹

Varieties of Commercial Flax.—By far the largest proportion of the flax used in Europe is grown in Russia, though Belgium and Ireland are also great flax-producing countries.

The fine cream-coloured flax grown near Courtrai in West Belgium has the reputation of being the best in the world, its excellence being usually attributed to the particularly suitable fermentation which occurs during its *retting* in the slow-moving waters of the River Lys. The flax grown in Waes is of a darker colour, while that of Brabant is so dark that it is known as "blue flax".

The following list of varieties of imported flax with their distinguishing marks was prepared for the U.S. Department of Agriculture (loc. cit.)—

Russia.—Russian flax is known as *Slanetz* (or dew-retted) and *Motschenetz* (water-retted), and the shipments from St. Petersburg are largely of *Stretz* or ungraded kinds of several districts. The flax from these districts is known under the name of Bejodsk, Krasnoholm, Twer, Kashin, Gospodsky, Nerechta Wologda, Jaraslaw, Graesowtz, Kostroma—all *Slanetz*. The *Motschenetz* sorts are Pochockon, Ouglitz, Rjeff, Jaropal and Steppurn. From Archangel are shipped *Slanetz* sorts known as First Crown, Second Crown, Third Crown, Fourth Crown, First Zabrack and Second Zabrack. From Riga shipments are entirely of *Motschenetz* sorts, and the marks are graded from the standard mark K, the others being HK, PK, HPK, SPK, HSPK, ZK, GZK, and HZK.

Holland.—Dutch flax is graded by the marks $\frac{I}{V}$, $\frac{II}{V}$, VI, VII, VIII, IX.

Belgium.—Flemish flax (or blue flax) includes Bruges, Thussalt, Ghent, Lokeren, and St. Nicolas, and is graded $\frac{II}{IV}$, $\frac{I}{V}$, $\frac{II}{V}$, VI, VII, VIII, IX.

Courtrai flax is graded $\frac{I}{III}$, $\frac{II}{III}$, $\frac{I}{IV}$, $\frac{II}{IV}$, $\frac{I}{V}$, $\frac{II}{V}$, VI. Fernes and Bergues

flax is graded A, B, C, D. Walloon flax is graded II, III, IV. Zeeland flax is graded IX, VIII, VII, VI. Friesland flax is graded D, E, Ex, F, Fx, Fxx, G, Gx, Gxx, Gxxx.

France.—French flax is known by the districts of Wavrin, Flines, Dourai, Hazebrouck, Picardy and Harnes.

¹ "Report No. 10, U.S. Dept. of Agriculture" (Office of Fibre Investigations), p. 77.

Ireland.—Irish flax comes as scutched and mill-scutched, and is known by the names of the counties where raised

Canada.—Has no standard of marks or qualities

The Retting of Flax.—After the flax has been *ripled* to separate the stalk from the seed, a process effected by means of iron combs, it is steeped or *retted* to separate the bast fibres from the ligneous portion.

The process of *retting* (or rotting) is, in the main, a slow bacterial decomposition, which is carried out either in tanks or running streams (*water-retting*), or by exposure to atmospheric influences (*dew-retting*), or by both (*mixed retting*).

A process introduced in 1891 by Loppens and de Swarte (Eng. Pat., 1895, 14,781) accelerates the retting while obviating the drawback of polluting a river with decomposing vegetable matter, and is claimed to give as good results with any water as those obtained in the River Lys. In this process the flax straw is placed upright in a tank through which passes an upward current of water. The substances dissolved form a heavy solution which falls to the bottom, its place being continually taken by fresh water from below.

The nature of the bacterial change in *retting* has been studied by Beijerinck and van Delden,¹ who find that it is essentially a fermentation of the pectose in the cells about the bast fibres, first into pectin and then into sugars, brought about by an enzyme, *pectinase*, secreted by the bacteria, and promoted by frequent changes of water in the first stages of the decomposition.

The specific micro-organism is *Granulobacter pectinovorum*, and it is accompanied by a less active bacillus *G. urocephalum*. Certain aerobic bacteria (e.g. the hay bacillus) have also a slight retting action, but acetic and lactic acid bacteria are inactive.

Cottonised Flax.—About the year 1851 Claussen introduced a method of disintegrating flax by chemical means into a fine cotton-like material. The flax was first treated with a weak solution of caustic soda, then impregnated with sodium bicarbonate solution, and immersed in very dilute sulphuric acid, the

¹ "Woch. für Brau.," 1904, xxi. p. 85.

carbon dioxide liberated within the fibres effecting the decomposition.

During the Civil war in America various attempts were made to replace cotton by fibre prepared in this or a similar way from linen, the products being known under various names such as "fibrilia," "flax cotton," "Claussenised flax," and "flax wool".

As the fabrics woven from this material were found to be deficient in strength the process was soon abandoned.

Lustrous Linen.—Some varieties of flax possess a greater natural lustre than others. A silken lustre is also imparted to linen in the same way as in the case of cotton by mercerisation and by sizing and polishing (p. 109).

Use of Linen as a Textile.—The remote antiquity of the use of linen as a textile material is shown by the frequent references to flax in the Old Testament and in Herodotus,¹ where it is mentioned as being an article of export from Egypt.

These statements are borne out by the fact that all the Egyptian mummy clothes examined by Thomson,² and subsequently by others, were found to consist solely of linen.

Flax continued to be exported from Egypt until about the 14th century, and was a main source of the supply for European countries.

As was mentioned above, flax was used as a textile in the ancient Swiss lake dwellings, and was probably extensively cultivated as a domestic industry throughout Europe long before the establishment of the thriving industries of France and Flanders.

The cultivation of flax in France was developed by Charlemagne in the 8th century, and two centuries later markets were established in Bruges, Courtrai, and other towns in Flanders for the sale of various products and especially linen.

From that time onwards linen became by far the most important vegetable textile material in Europe, until in the 18th century it was slowly displaced by cotton.

The introduction of the use of flax into England is attributed to the Romans; but although the plant was grown on a small

¹ "Herodotus," ii. p. 105.

² "Phil. Mag.," 1834, v. p. 355.

scale, chiefly as a home industry, its cultivation never attained much importance, and during last century steadily declined.

In Ireland it attained a much more important position than in this country.

The development of the Irish linen industry is attributed to bounties given by William III. to encourage the manufacture, as well as to enactments prohibiting the manufacture of wool in Ireland as an interference with the English woollen trade.

The manufacture of linen in Scotland, introduced early in the 18th century, made but little progress notwithstanding the aid from bounties granted by a Board of Supervision appointed in 1827.

In North America the use of flax appears to have been introduced by the first colonists, and by the beginning of the 17th century the manufacture of linen was well established as an industry in Massachusetts. During the latter half of the last century there was a gradual but steady decline in the amount of linseed grown in the older States, but of late increased attention has been given in the Western States to the cultivation of flax for the fibre.

Characteristics of the Fibre.—*Dimensions*—According to Wiesner¹ the flax fibre ranges in length from 20 to 140 cm and in breadth from 0·012 to 0·025 mm, the average being 0·016 mm.

Hanausek² gives the length of the industrial fibre as 20 to 150 cm., while Dodge³ gives the following dimensions. Length 5·107 to 2·598 in (average about 1 in.); diameter, 0·0006 to 0·00148 in. (average about 0·001 in.).

Structure.—The fibre is made up of bundles of colourless tapering cells, which, according to von Hohnel, vary in length from 4 to 66 mm (average 25 to 30 mm.), and in diameter from 12 to 30 μ . The cells may be isolated by treatment with a dilute solution of chromic acid. The longitudinal and transverse fissure markings upon their surface are rendered more distinct by treatment with a solution of iodine and zinc chloride.

¹ "Rohstoffe des Pflanzenreichs."

² "Lehrbuch der Techn. Mikrosk.," 1891, p. 68.

³ "U.S. Dept. Agriculture, Report," 10, p. 221.

The fibres are regularly constructed with pointed ends, and are, as a rule, thickened so that the lumen has the appearance of a thin line.

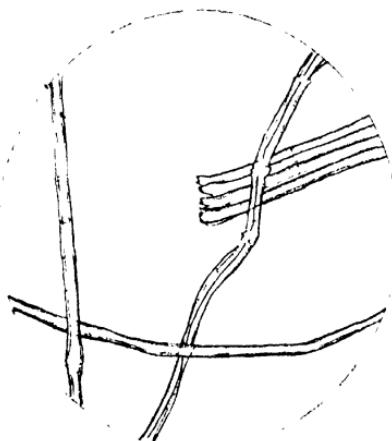


FIG. 47.—Flax Fibres.

There are numerous cross markings, which may possibly be pores, and here and there knot-like joints are seen.

The cross section of the fibre is very characteristic, showing small groups of straight-sided polygons, and is quite distinct from the irregular form shown by the cross section of hemp.

It has been shown by Herzog¹ that in certain flax fibres derived from the lower part of the stem of the plant and from the root, the lumen is wide. Such fibres are, as a rule, made into tow, and might be mistaken for hemp, but for the fact that they still retain portions of the epidermis of the plant-stem.

Action of Reagents.—By treating the flax cells with a very dilute solution of iodine the outer portion is stained dark blue, while the lumen, containing the protoplasm, appears as a yellow line surrounded by a light blue zone.

Cuprammonium solution causes the fibre to swell up, leaving the lumen as a fine crinkled thread.

¹ "Oest. Chem. Zeit.," 1898, i. pp. 310, 335.

Hanausek¹ recommends the use of a solution of potassium bichromate containing an excess of sulphuric acid as a reagent for distinguishing between linen and hemp under the microscope. The fibres of the former swell up more rapidly than those of the latter, and the dark patches formed upon the surface are more pronounced. The lumen has the same appearance as after treatment with cuprammonium solution, being wavy, irregular and broken, while in the case of hemp it is continuous, and not broken or undulating.



FIG. 48.—Mercerized Linen.

Iodine and sulphuric acid give a blue coloration resembling that obtained with cotton, but appearing more slowly.

Fuchsin followed by ammonia solution stains unbleached linen a persistent pink colour, and the test may be used to distinguish between flax and cotton. Bleached linen, however, behaves like cotton towards the reagent.

Physical Properties.—The strength of the flax fibre is considerably greater than that of cotton, but it is more easily disintegrated and injured by bleaching and oxidising reagents than the latter. Flax that has been over-retted is also brittle.

¹ "Zeit. Farb. Ind.," 1908, vn. p. 105.

According to de Mosenthal¹ the specific gravity of linen is 1.548, that of undried cotton being 1.523 to 1.525, and that of thoroughly dried cotton 1.607 to 1.610.

The finest flax is of a faint yellowish tint, while that retted in stagnant water is gray or dark gray owing to the action of the products of decomposition.

Composition.—Linen, like cotton, consists chiefly of cellulose, which constitutes up to about 90 per cent. of its dried substance. It also contains 2 or 3 per cent. of fat and "wax," 4 or 5 per cent. of substances soluble in water, and about 1 per cent. of mineral matter, the remainder of the solid constituents consisting of pectose bodies, lignin, etc.

Muller gives the following analyses to two varieties of Belgian huckled flax:—

Flax.	Water	Ash.	Extractives	Fat and "Wax"	Cellulose.		Intercellular Substance and Pectose Bodies.
					Per cent.	Per cent.	
1	8.65	0.70	3.65	2.39	82.57	2.74	
2	10.70	1.32	6.02	2.37	71.50	9.40	

There is not much lignin (woody fibre) in flax, but as Hohnel has shown, there are short spaces on the fibre which are strongly lignified. Most of this lignin is removed in the process of bleaching, and the fibre becomes softer and more elastic.

It is possible to distinguish between unbleached flax and hemp by a determination of the methyl value (see p. 15).

Moisture.—The proportion of hygroscopic moisture in linen is about 7 or 8 per cent., or about the same as in cotton. The Turin Congress fixed 12 per cent. as the amount of regain for linen.

A specimen of Indian flax examined by Cross and Bevan² gave the following values. Moisture, 9.3; ash, 1.6; α -hydrolysis (loss) 14.6; β -hydrolysis (loss) 22.2; acid purification (loss) 4.5, and cellulose, 81.9 per cent.

¹ "J. Soc. Chem. Ind.," 1907, p. 443.

² "Indian Fibres," p. 9.

Flax wax.—According to Hoffmeister¹ the odour and the suppleness of flax are to be attributed to a characteristic wax-like substance upon the surface of the fibres, which, after its removal by means of a suitable solvent, are rough, lustreless and brittle.

The wax-like residue left on evaporation of the solution obtained on extracting the flax with ether is a white, yellowish-green, or brown substance with a strong odour of flax. It is insoluble in water, has a specific gravity of 0·9083 at 15° C., and melts at about 61·5° C. It consists in the main, of about 70 to 80 per cent. of a paraffin resembling ceresin, mixed with the glycerides of several fatty acids, and also contains phytosterol and ceryl alcohol, and a small proportion of a volatile aldehydic substance.

The amount of wax appears to stand in some relationship to the fineness and degree of purity of the fibres, a large yield being obtained from imperfectly cleansed flax, apparently being derived from the cuticle of the plant. The so-called "flax-dust" from the factory was found by Hoffmeister to contain 10 per cent. of the wax.

RAMIE.

Source.—The commercial fibre known as *ramie* or *China grass* is derived from plants belonging to the *Urticaceae* or nettle family, the members of which are distinguished by the strength and durability of the bast fibres of their stalks.

In former centuries fibres for spinning were obtained from the common stinging nettle (*Urtica dioica*), and attempts are now being made, with the aid of modern machinery, once more to utilise this plant as a source of textile material.²

The stingless nettle, cultivated in China from time immemorial is *Boehmeria nivea*, a small shrub growing to a height of 5 to 8 feet, and producing leaves the upper side of which are white.

Another variety of the plant, *B. nivea*, var. *tenacissima*, grows

¹ "Ber. d. d. chem. Ges.," 1903, xxxvi. p. 1047.

² Hanausek, "Lehrbuch der Techn. Mikrosk.," p. 83.

in the more tropical parts of China, and produces larger leaves, green on both sides, and tougher fibre.

Morris¹ suggested that the name of *China grass* should be reserved for the former, and that the other variety should be designated as *rhea* or *ramie*.

In practice, however, the three names are commonly used indiscriminately, though the fibre of "China grass" differs from that of the coarser plant in being finer and more suited for manufacture into textile fabrics. Both kinds are common throughout the countries of Eastern Asia, and other species are cultivated in the United States. The plant is of rapid growth, and yields three, four, or even five crops in a year without re-planting.

Preparation.—The fibre is stripped from the stalk of the plant either by hand-labour, which is still the only method employed in China, or by boiling the stalks in water or a solution of a suitable salt and subsequently separating the fibre by hand, or entirely by machinery, as in the European and American processes.

In the Chinese method the crude material termed *black ribbon*, is scraped, yielding a relatively clean long fibre known as *yellow ribbon*, only about 11 per cent of the latter being obtained from the plant stems.

The methods of "degumming" the crude fibre to render it suitable for spinning are guarded as secrets. They probably consist in the main in a process of treating the fibre under pressure with a solution of caustic alkali or alkali oleate, followed by combing or carding, and bleaching.

The term "cottonised" ramie is often restricted to material, the fibres of which have been disintegrated by too prolonged action of the "degumming" agents.

Historical.—Ramie was introduced into England in 1810 by John Marshall, who attempted to manufacture it into textiles in Leeds. Similar attempts to utilise it were made about 1836 in France. In 1855 it was introduced into America, but did

¹ "Useful Fibre Plants of the World" (U.S. Dept. Agriculture), p. 86.

not attract any notice until about ten years later, when the first ramie machines were exhibited.

In India attempts at mechanical separation were made as far back as 1816, but these were unsuccessful, and little further interest appears to have been taken in the possibility of producing ramie as a commercial fibre, until 1869 when a reward of £5,000 was offered by the Indian Government for a decorticating machine. During the following years many machines competed for the prize, but as none of them proved satisfactory in the trial experiments the money offer was withdrawn in 1879.

The public interest aroused by these experiments extended to this country, and during the last thirty years of the nineteenth century several companies were formed to deal with ramie as a commercial product. None of these were successful, however, and no fewer than seven firms are said to have been ruined in the attempts, the loss of capital being upwards of £250,000.

In Germany some of the attempts have been attended with more success, partly owing to the advantage of cheaper labour, but chiefly to the public's accepting more readily a novel material.

Since the discontinuance of the official Indian trials a long succession of inventions for the decortication of ramie has been published, many claiming to have solved the economic problem of reducing the cost of production of ramie to such an extent as to enable it to compete on its merits with cotton.

Some of the modern decorticating machines employed in working up the material from the extensive ramie plantations in the Southern and Pacific Coast States of North America are said to be working effectively, and to have removed one of the main barriers that have prevented the rapid growth of the industry.

Properties.—Crude ramie fibre is characterised by its strength, which far exceeds that of flax or hemp. According to Alcan's¹

¹ Wiesner, "Die Rohstoffe des Pflanzenreiches," n. p. 326.

comparative measurements, taking its tenacity as unity, that of flax is 0.25; that of linen, 0.33; and that of cotton, 0.33; while the relative elasticity of the four fibres may be represented as 1; 0.66; 0.75; and 1 respectively.

Before being degummed, the crude fibre or bast consists of greenish-yellow ribbons made up of a number of fibres, while the fine silky fibres prepared for spinning consist of single isolated cells or of small bundles of cells.

Ramie fibres are usually from 15 to 25 cm. in length, though individuals may be as long as 58 cm., while in breadth they range from 20 to 80 μ .

According to Vétilhart¹ the fibres vary from 6 to 25 cm. in length, and from 0.05 mm. to 0.08 mm. in diameter.

Ramie fibres are thus the broadest of ordinary industrial bast fibres.

The cell walls are comparatively thick and appear wider than the lumen. They are folded over in a characteristic

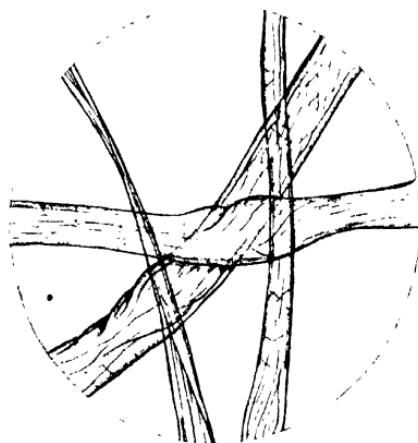


Fig. 49.—Ramie Fibres.

fashion; with the result that viewed from the other side the lumen appears as a narrow line.

According to Hassack the lumen varies from 21 to 45 μ in

¹ "Études sur les Fibres Végétales," p. 99.

width, or from $\frac{1}{2}$ to $\frac{1}{3}$ of the total breadth, while the width of the cell wall is about $9\ \mu$.

The surface of the fibre is marked by striations crossed in places by transverse darker lines. These distinctive markings and the folded walls are valuable means for differentiating ramie from the more common textile fibres.¹

The lumen contains fine granular protoplasm of a light yellow colour. On treatment with iodine it becomes violet, a reaction not hitherto observed in the case of other vegetable fibres (Wiesner, loc. cit.).

Transverse sections may show a single cell or, more often, four or more cells of irregular polygonal form united together. On treatment with iodine and sulphuric acid they show an outer dark blue zone, an inner narrower lighter blue zone, and a greenish-yellow inmost portion.

Composition.—According to Wiesner air-dried ramie contains about 6.5 per cent. of moisture, which increases to about 18 per cent. after exposure for twenty-four hours in a moist atmosphere at 20° C .

Muller gives the following analyses of China grass (*B. tenacissima*, white ramie) and of ramie (rhea, green ramie, *B. nivea*) :—

	Water	Ash.	Aqueous Extract.	Fat and Wax.	Cellulose.	Intercellular Substance and Pectins.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
China Grass	9.05	2.87	6.47	0.21	78.07	6.10
Ramie	10.15	5.63	10.34	0.59	66.22	12.70

A specimen of the crude yellow ribbon examined by us contained 16.9 per cent. of water, and 3.71 per cent. of ash, 0.55 per cent. of the latter (calculated on the fibre) consisting of phosphoric acid (P_2O_5).

Slight lignification of ramie is indicated by the fact that it

¹ Hassack quoted by Hanausek, *loc. cit.*, p. 85.

gives a faint yellow coloration with aniline sulphate, and that in the methyl iodide test Herzog obtained a methyl value of 0·77, corresponding to 1·46 per cent. of lignin.

The main constituent of rannie is cellulose of the same type
• as that of cotton and linen.

CHAPTER IX.

JUTE, HEMP AND OTHER FIBRES USED FOR CORDAGE, ETC.

JUTE.

Source.—Jute is the bast fibre of several species of *Corchorus*, cultivated in India and tropical countries generally. The bulk of the world's supply is furnished by *C. capsularis* and *C. olitorius*, both originally indigenous to India. A smaller amount of fibre is furnished by two other species, *C. fuscus* and *C. decemangulatus*.

There are also a large number of wild varieties, which have as yet been little used as the source of jute.

Of the two most important cultivated species the best fibre is produced by *C. capsularis*. The seed of this is sown about April, and the plants are cut about September, when the fruit ripens. They are then from 10 to 12 feet in height.

The cut stems, after removal of the leaves, are left for three or four days in the field, and are then retted for three to thirty days in a sluggish stream. The fibres are next separated by hand or machinery, washed and dried on lines. The finer fibre is exported in that form, while the coarser material is generally made up into sacks on the spot.

Historical.—Jute has been in use for centuries in India, though its first introduction into Europe only dates back to the latter part of the eighteenth century. The name by which it is now universally known was that chosen by Roxburgh in 1795 from various Indian names for the fibres.

The samples first sent over to this country attracted but little attention, and it was not until after 1830 that jute was spun in any considerable quantity in Dundee.

The development of the jute industry in this country was greatly stimulated by the scarcity of Russian hemp during the Crimean war, and, later, by the cotton famine caused by the American Civil war.

The industry in Germany and Austria did not attain any degree of importance until after 1860, and the use of jute then became slowly known in other parts of Europe. To protect her flax industry Russia imposed a considerable duty on the imported fibre.

Commercial Varieties.—A description of the varieties most commonly met with in the Indian trade is given by Kerr ("Report on Jute in Bengal," 1874). The best variety known as *Uttariya* or *Northern Jute* is long and of good colour and strength, though not so soft as *deswal* and *desi* jute. A coarse black jute known as *deora* is used for rope-making, while *bhatial* is also in demand for the same purpose. *Janjupuri* jute is short in fibre and weak and of little value for spinning.

In trade the different qualities are known as fine, medium, common, poor, rejections and cuttings.

Most of the jute of commerce passes through Calcutta, whence the origin of the name *Calcutta hemp* frequently applied to jute. It is usually exported in the unbleached condition. Bleached jute, which is produced at Dundee, has a more silken lustre than the unbleached fibre, and is woven into textiles.

The refuse from the spinning of jute is mixed with similar refuse from flax and hemp, and manufactured into a woolly product sold as *Kosmos fibre* or *artificial wool*. The butts or cuttings are used for coarse sacking and in the manufacture of packing paper.

Properties.—Prepared jute fibre as met with in commerce ranges from about 4·5 to 8 feet in length. Some of the crude fibres, however, are as long as 14 feet. In general the products from *C. capsularis* are longer than those from *C. olitorius*.

The fibre varies considerably in breadth, the parts derived from the upper part of the stem being finer than those from the lower part. According to Wiesner the average thickness is about 80 μ .

The specific gravity of jute fibre containing 7 per cent. of moisture was found by Pfuhl¹ to be 1.436 compared with water at 4° C. Fibre purified by treatment with alkali had a specific gravity of 1.587 (Cross and Bevan).

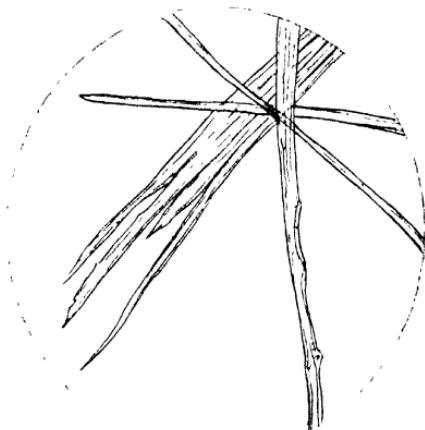


FIG. 50.—Jute Fibres.

The colour of freshly separated jute varies from white to pale yellow or grey, the lower parts of the fibres being always darker. In some sorts of jute the colour changes to dark brown after exposure to the air.

The best kinds of jute have almost a silk-like lustre, in which respect they are superior to hemp. In strength of fibre jute resembles cotton and flax, but is much inferior to hemp.



FIG. 51.—Cross-section of Jute Fibres.

Microscopical Appearance.—Externally the fibre is smooth and does not show jointed ridges or transverse markings. Only in the finest qualities are the bundles of fibres so far separated as to show isolated cells.

The appearance of a cross section of the fibre is very characteristic, consisting of groups of polygonal cells, with straight sides and sharp

¹ "Physikalische Eigenschaften der Jute," 1888, p. 23.

angles. The lumen is oval or circular and as a rule fairly wide though it varies considerably in size, and sometimes almost disappears. The isolated bast cells vary in length from about 0·8 to 4·1 mm., and from about 17 to 23 μ in breadth. The want of parallelism between the inner and outer walls of the cell is a characteristic mark of jute.

According to Wiesner¹ there is but little variation in the dimensions of the cells isolated from the four species of jute.

Chemical Composition.—The following analyses of various kinds of jute are given by Muller:—²

	Long Fibres.		Brown Cuttings
	Nearly Colourless.	—	
Ash	0·68	—	—
Moisture	9·93	9·64	12·58
Aqueous Extractives	1·03	1·63	3·94
Fat and Wax	0·39	0·32	0·45
Cellulose	64·24	63·05	61·74
Incrusting and Pectinous Substances	24·41	25·36	21·29

✓ **Moisture.**—Jute exposed in moderately dry air will contain from 6 to 8 per cent. of moisture. According to Pfuhl fibre exposed to an atmosphere containing 71 per cent. of moisture will have 14 per cent. of moisture, while in an atmosphere saturated with steam it will absorb up to 34·25 per cent. (calculated on the dry substance).

The amount of regain for the conditioning of jute was fixed at 13 $\frac{1}{4}$ per cent. by the Turin Congress.

The ash in completely dry jute ranges from about 0·9 to 1·75 per cent.

A specimen of Indian jute examined by Cross and Bevan³ gave the following results: Moisture, 10·3; ash, 1·1; α -hydrolysis (loss), 13·3; β -hydrolysis (loss), 18·6; cellulose, 76·0; and acid purification (loss), 2·5 per cent.

¹ *Loc. cit.*, n. p. 339. ² "Pflanzenfaser," p. 59.

³ "Report on Indian Fibres," 1886, p. 9.

sample of *Corchorus* fibre of the jute class from Sierra Leone examined at the Imperial Institute gave the following values: Moisture, 11.9; ash, 0.4; α -hydrolysis (loss), 7.4; β -hydrolysis (loss) 10.5; and cellulose, 79.9 per cent. Length of ultimate fibre, 1.4 to 3.0 mm. This fibre contained more moisture and was weaker than good jute.

✓ **The Cellulose of Jute.**—Jute fibres differ from the fibres of cotton, linen and ramie in consisting in the main of a compound of cellulose known as *lignocellulose*. This difference is indicated by a difference in elementary composition, and by several characteristic reactions.

Thus jute fibre contains from 46 to 47 per cent. of carbon, 5.8 to 6.1 per cent. of hydrogen, and 47.2 to 47.9 per cent. of oxygen (Cross and Bevan).

Separation of Cellulose.—The cellulose in jute and similar fibres may be separated from its non-cellulose associate (*lignone*) by treatment with chlorine, which combines with the lignone to form a compound soluble in a solution of sodium sulphite. The following method is substantially that described by Cross and Bevan¹: A weighed quantity of the fibre (5 grms.) is dried in the water-oven, and then boiled with a 1 per cent. solution of sodium hydroxide for half an hour, the evaporated water being meanwhile continually replaced. The mass is now removed, and, after expression of most of the water it retains, is subjected to the action of a current of chlorine for thirty minutes to an hour, after which it is washed, and treated with a 2 per cent. solution of sodium sulphite, which is slowly heated. When the liquid boils 0.2 per cent. of sodium hydroxide is added, and the boiling allowed to proceed for five minutes. The residue, which consists of nearly pure cellulose, is washed with hot water, further purified by treatment for a few minutes with a 0.1 per cent. solution of potassium permanganate, again washed, pressed, dried and weighed.

Bromine also combines with the lignone, but as it also acts upon part of the cellulose, the yield by the chlorine method is from 2 to 5 per cent. higher.

Furfural-producing Constituents.—The lignone or non-cellulose portion of the ligno-cellulose of jute contains certain groups which yield furfural on treatment with dilute hydrochloric acid, and this body may be estimated in the form of its hydrazone.

*Cross and Bevan's Method of Estimating Furfural in Jute.*²—The

¹ "Cellulose," p. 94.

² *Ibid.*, p. 99.

weighed substance (5 grms.) is heated with 100 c.c. of 12 per cent. hydrochloric acid (sp. gr. 1.06) in a flask connected with a condenser and the tube of a stoppered separating funnel. The distillation should be made to proceed at the rate of 2 c.c. per minute, and successive portions of 30 c.c. each collected, until aniline acetate and hydrochloric acid no longer give a rose coloration.

The distillate is now treated with a slight excess of sodium carbonate, then acidified with acetic acid, and made up to a definite volume by the addition of sodium chloride solution containing approximately the same amount of salt as has been formed in the distillate.

It is next treated with an aqueous solution of phenylhydrazine containing 12 grms. of the base and 7.5 grms. of glacial acetic acid in 100 c.c. and set aside. The precipitated hydrazone is washed, dried, preferably at 60° to 70° C. in a vacuum, and weighed. Its weight multiplied by the factor 0.538 gives the amount of furfural.

Lignocelluloses.—Lignocelluloses react with various aromatic compounds to form coloured derivatives. Thus they give a crimson colour with phloroglucinol and hydrochloric acid, a yellow colour with phenylhydrazine, and a crimson colour with dimethyl-*p*-phenylenediamine.

Phloroglucinol Absorption of Lignocelluloses—It has been shown by Cross, Bevan and Briggs¹ that there is a definite absorption of phloroglucinol by lignocelluloses, and they have devised the following method of determining this absorption:—

Forty c.c. of a solution of phloroglucinol (2.5 grms. in 100 c.c. of hydrochloric acid of sp. gr. 1.06) are mixed with 2 grms. of the material, previously dried at 100° C., and the liquid filtered through cotton wool after standing for twelve hours. Ten c.c. of the filtrate are then titrated with a standard solution of furfural or formaldehyde, and the difference between the result and that obtained with 10 c.c. of the original phloroglucinol solution affords a measure of the absorption. The standard solution for the titration contains 2.0 grms. of furfural or 40 per cent. formaldehyde solution in 500 c.c. of hydrochloric acid of sp. gr. 1.06. The 10 c.c. of phloroglucinol solution are diluted with 20 c.c. of the hydrochloric acid, and heated to 70° C., and the aldehyde solution added at the rate of about 1 c.c. every two minutes until the whole of the phloroglucinol has been precipitated, and the liquid no longer gives a red coloration when dropped on inferior newspaper.

Tested in this way wood pulp absorbed 7.5 per cent., jute, 4.2 per cent.; esparto cellulose, 0.5 per cent.; and cotton, 0.2 per cent. of phloroglucinol.

If the furfural value of the phloroglucinol solution is found gravimetrically

¹ "Chem. Zeit.", 1907, 31, p. 725

ally, the solution may be used for the estimation of the amount of furfural produced by the pentosans in a substance.

Chemical Reactions.—Owing to this pronounced lignification, which Wiesner claims to have been the first to discover, jute in the unbleached condition may be readily distinguished from flax or cotton.

Thus all varieties of jute give bright yellow or orange colorations with aniline sulphate, whereas hemp only gives a relatively slight yellow coloration.

Iodine colours jute yellow, the colour becoming darker on the addition of sulphuric acid. After treatment with chromic acid or potassium hydroxide solution, however, jute gives a blue coloration with iodine and sulphuric acid.

The use of iodine in distinguishing jute from Manila hemp and *Adansonia* fibre is described below.

Jute is acted upon to a greater extent than cotton or linen by chemical agents, such as alkalies or bleaching substances. Cross and Bevan¹ point out that bleaching processes tend to disintegrate fibres into their individual cells. Hence jute, the ultimate fibre cells of which measure only about 4 mm., will obviously be more affected than flax which has an ultimate fibre cell measuring about 40 mm., or about as long as that of cotton.

Matthews² describes experiments in which jute and other fibres were exposed for two hours to the action of steam under a pressure of two atmospheres. Jute lost 21.39 per cent. in weight, or three times as much as hemp, Manila hemp or coir. The loss from flax was a little less than 4 per cent., and that from ramie under 1 per cent.

Cuprammonium solution causes the fibres to swell to some extent and colours them blue. Previous treatment with iodine and sulphuric acid renders them completely soluble in the reagent (Wiesner).

¹ "Report on Indian Fibres," p. 17.

² "Textile Fibres," p. 289.

HEMP.

Source.—The bast fibres of the hemp plant *Cannabis sativa* have been used for many centuries for making ropes and sail-cloth, whilst the finer sorts have been spun into yarns and woven into textiles.

According to Wiesner¹ there is only one species of hemp used for this purpose, and *C. indica*, which is often mentioned as a source of hemp, must be regarded as only a variety of *C. sativa*. It produces more narcotic principles than the ordinary plant, and is cultivated in India as the source of *bhang*, but its bast fibre is greatly inferior to that of *C. sativa*. The hemp plant has a long straight stem, and produces bunches of long dentated leaves having a characteristic odour.

The male plant, which goes by various names (*Summer hemp*, *Staubhanf*, *Hanf*) yields better fibre than the female plant (*winter hemp*, *bastling*, *Hanfhenne*), which is, as a rule, not cut before the fruit period, when the fibres have become strongly lignified. The fibre from plants that have produced seed is of little value.

The fibre is separated in the same manner as flax by retting, which is usually done in cold water, after which it is broken, scutched and heckled. About sixty-five parts of combed fibre and thirty-two parts of tow are obtained from 100 parts of raw fibre.

The broken hemp is termed *bast hemp*, while the heckled product is known as *pure hemp*, and the latter is further classified into *spinning hemp* and *cobbler's hemp*, according to its quality.

Historical.—Hemp is stated to be indigenous to Persia, but its probable origin was India, where it was cultivated as early as 800 to 900 B.C. According to Herodotus (iv. 75) the Thracian women made themselves, from hemp, garments which were hardly to be distinguished from those of flax.

Of the Roman writers Pliny (xix) makes mention of the cultivation of hemp.

Hemp was grown at an early period in the south of France

¹ *Loc. cit.*, ii. p. 300.

and in Slavonic countries, and thence its cultivation spread to other parts of Europe, and especially to Russia, where large quantities are still grown.

Africa (especially Egypt and Algiers), North America and more recently Australia, also produce considerable quantities of hemp.

Varieties of Hemp.—In addition to common hemp several varieties of the plant are cultivated in Europe. Of these, mention may be made of Bologna or Piedmontese hemp, distinguished by its beautiful silken lustre, of Chinese hemp, small hemp and Arabian hemp, the plant which yields the narcotic substances made into *haschisch*.

French hemp is superior to that produced in Russia.

Many plants, of distinct species from hemp, yield a fibre, which is frequently described in commerce as *hemp*, though usually with a prefix, such as Cebu hemp (from *Musa textilis*), Cretan hemp (from *Datisca cannabina*), etc. A long list of these plants is given by Dodge.¹

Properties.—Commercial fibres vary considerably in length, but usually measure from one to two yards.

The Italian varieties often exceed two yards, while the giant hemp from Africa often exceeds three yards in length.

The best sorts of hemp are light grey in colour, those of greenish tint coming next in value, and those of dull yellow being the poorest.

As a rule hemp is much coarser than flax, though some of the Italian products are nearly as fine.

Microscopical Appearance.—The bast cells of hemp are very long, the length varying from 10 to 50 mm. According to Vétillart, the breadth of the cell varies from 16 to 50 μ , with an average of 22 μ .

The fibre is uneven in diameter, and often shows jointings and longitudinal markings. It is not always easy to distinguish between linen and hemp, though fragments of parenchymatous tissue which are sometimes found adhering to the latter but never to the former sometimes affords help.

¹“Useful Fibre Plants of the World,” p. 190.

The ends of the fibres are usually blunt, but are occasionally pointed and sometimes forked. This forking is characteristic of hemp, and does not occur in linen.

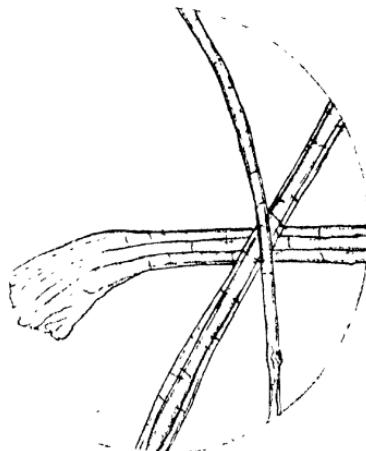


FIG. 52.—Hemp Fibres.

Hanausek¹ found that it was present in about one fibre in ten, and that the tendency was more pronounced the further south the origin of the hemp.

The cross section is very characteristic, showing groups of adherent cells with three, four, or six sides, and usually with rounded angles very distinct from the pointed angles of jute cells. The median layer between the cells is coloured yellow by iodine and sulphuric acid.

The lumen sometimes has a forked appearance, and its diameter is usually about one-third that of the cell.

Chemical Composition.—Hemp often contains more moisture than cotton or linen. Thus under parallel conditions Matthews found 8 per cent. in hemp as compared with 6 per cent. in cotton.



FIG. 53.
Cross-section
of Bundle
of Hemp
Fibres.

¹ "Techn. Mikroskopie," p. 73.

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¹“Useful Fibre Plants of the World,” p. 190.

In addition to *A. rigidula*, there is a false sisal hemp derived from *A. decipiens*, which grows wild along the coast of Florida. It may be distinguished from the true sisal hemp by having lighter and softer leaves with thorny edges. The fibre is much weaker than that of *A. rigidula*.

Another agave, *A. heteracantha*, yields a stiff fibre known as *Tampico* or *Mexican fibre*. This is used in the manufacture of cheap brushes (see IXTLE FIBRE).

The leaves are taken from the plant at about the third year of its growth. The pulp is scraped away by machinery, and the residual fibres washed and dried in the sun. A plant usually yields about 0·75 kilo. of fibre.

Properties.—Sisal hemp is composed of straight, smooth, light yellow fibres ranging from $2\frac{1}{2}$ to 4 feet in length.

It is inferior to Manila hemp in strength and is also less flexible. It has also the drawback of being disintegrated by salt water more rapidly than other fibres used for ropes.

Microscopical Characteristics.—The technical fibre is composed of bundles of cells, from 1·5 to 4 mm. in length and 20 to $32\ \mu$ in breadth. As a rule the ends are blunt, and the forking frequently noticeable in ordinary hemp is seldom to be observed.

Characteristic spiral formations are of frequent occurrence, and calcium oxalate crystals derived from the parenchyma cells may often be seen attached to the surface of the fibre. When the fibre is ignited the crystals appear as glistening points of crystalline calcium carbonate in the ash.

The lumen varies considerably in diameter and sometimes exceeds the width of the wall of the cell.

In cross section the fibre shows groups of polygonal cells



FIG. 54.—Fibres of Sisal Hemp, and Cross-section of Fibres.

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¹“Useful Fibre Plants of the World,” p. 190.

A specimen of Indian agave examined by Cross and Bevan¹ gave the following results: Moisture, 10.5; ash, 1.4; α -hydrolysis (loss), 10.0; β -hydrolysis (loss), 20.0; cellulose, 75.8; and acid purification (loss), 1.1 per cent.

Analysis of various Indian agave fibres compared with the results given by specimens of Indian sisal hemp have been published by the Imperial Institute: —²

	Agave from Chalk magnum	Agave Cana from Madras	Sisal Hemp from Madras	Sisal Hemp from Banga lore	Agave Weight,
Moisture	9.1	9.1	9.3	9.3	9.9
Ash	2.5	3.4	1.5	1.2	2.6
α -hydrolysis (loss)	19.8	19.5	13.6	11.4	16.3
β -hydrolysis (loss)	21.4	21.6	16.9	16.0	18.7
Cellulose	71.4	72.5	75.7	77.6	75.2
Length of Staple, Feet	3.4	3.75-4.75	3.75-4.25	4.5-5	2.25
Comparative Strength	55.3	62.7	87.5	100	57.9

PITA FIBRE.

Pita fibre, which closely resembles sisal hemp in its general characteristics and microscopical appearance, is derived from the leaves of *Agave americana*, the *Maguey plant* of Mexico and Central America.

These grow abundantly in the waste places in Mexico, each plant producing some 40 leaves 8 to 10 feet long by one foot in width, and yielding about 10 per cent of fibre.

There is some confusion with regard to the plants producing the commercial fibre. This is said to be derived also from *Agave saxi*, termed *henequen* by the natives, while the term *iztle fibre* is sometimes given to the fibre of *A. americana* instead of being restricted to the product of *A. heteracantha*.

Pita fibre is also sold under the name of *Aloe fibre*.

It is largely employed in the manufacture of twine and cordage, and as the material for a fine kind of lace (*Fayal*).

¹ "Report on Indian Fibres," p. 9.

² "Bull. Imp. Inst.," 1906, 4, p. 23.

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¹“Useful Fibre Plants of the World,” p. 190.

air-dried fibre containing 12·9 per cent. of moisture contained 45 and 56·1 per cent. after exposure to an atmosphere saturated with steam:

The fibre elements, which may be readily isolated by treatment with chromic acid, vary from 2·0 to 2·7 mm. in length, and from 12 to 46 μ , usually 29 μ , in diameter (Wiesner). The ratio of the width to the length is about 1·250.

Examined under the microscope the separate fibres are seen to be of fairly uniform thickness and show a well-marked lumen, but few surface markings. In cross section they are seen to consist of more or less oval aggregates of cells in which the lumen is large and open.

Siliceous plate-like structures (*stegmata*) may frequently be seen attached to the fibre bundles. By extracting the fibres with nitric acid, then igniting them, and treating the ash with dilute nitric acid, the stegmata will frequently appear as a chain of beads.

Müller found a specimen of Manila hemp to have the following composition: Moisture, 11·85, ash, 1·02, aqueous extract, 0·97; fat, 0·63; cellulose, 64·72; and incrusting and pectinous substances, 21·83 per cent.

A specimen of Manila hemp examined by the present writers yielded 9·16 per cent. of moisture, 1·02 per cent. of ash, and 0·13 per cent of phosphoric acid (P_2O_5).

Iodine solution colours Manila hemp, while iodine in the presence of sulphuric acid gives a bright yellow or greenish coloration.

Aniline sulphate imparts a faint yellow tint, and phloroglucinol with hydrochloric acid a pale violet tint, to the fibre. The preceding reactions show that Manila hemp is lignified, though not to any very marked extent.

Characteristics of *Musa paradisiaca*.—The fibres of this plant

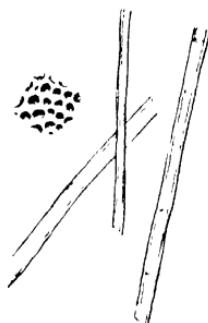


FIG. 55.—Fibres of Manila Hemp.

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¹“Useful Fibre Plants of the World,” p. 190.

FIBRE OF *ANDANSONIA DIGITATA*.

(Baobab Tree, Monkey-bread Tree.)

This fibre, known commercially as *Andansonia fibre*, is obtained from the inner bark of the baobab tree, *A. digitata*, which is indigenous to Africa, and is also cultivated in India and the West Indies.

It is prepared by cutting away the tough outer bark of the tree, and then stripping off the inner bark, beating the strips to remove pithy matter, and drying them in the sun (Watt).

The fibre is used as a raw material for paper

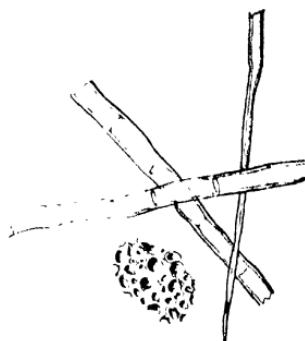
A sample examined by the writers and shown in the figure contained 10·15 per cent. of moisture, 7·62 per cent. of ash, and 0·29 per cent. of phosphoric acid (P_2O_5).

Differentiation of Jute, Manila and Andansonia Fibres.—These fibres, which closely resemble each other in microscopical character, are the chief fibres of non-European origin, used in the manufacture of packing paper. The jute employed for this purpose usually consists of the refuse from the spinning machines, while the chief source of the Manila is old ship's tow.

The table on page 166 gives the chief characteristics of the three fibres as observed by Dalen and Wishbar:—¹

Jute fibres are usually empty, while in Manila fibres there are frequently masses of protoplasm which give a yellow-brown coloration with a solution of iodine in zinc chloride solution.

Andansonia fibres show irregularities in diameter with sudden contractions near the ends. Ring-structures round the

FIG. 57. Fibres of *Andansonia Digitata*.

¹ "Mitt. kongl. tech. Versuchsanstalt, Berlin," 1902, 20, p. 51.

Fibre.	Coloration with Reagents.		Lumen	Ends	Pores	Subsidiary Constituents.
	Iodine in KI.	Iodine in $ZnCl_2$.				
Jute without lignin	Bright yellow-brown or brown	Yellow or brownish-yellow	Frequent change in diameter	Usually rounded	Openings parallel to axis	None
Manila	Grey, sometimes brown	Blue, sometimes red-violet	Frequent change in diameter	Usually rounded	Openings parallel to axis	None
Andansonia	Dirty grey and brown	Blue to red violet	Varying in breadth in thick-walled fibres ; regular in thin-walled fibres	Frequently pointed like lead pencil	Openings oblique to axis	Groups or single parenchyma cells with fairly thick oblique walls
			Width varies with fibres	Usually rounded	Openings oblique to axis	Calcified parenchyma cells and vascular fragments

fibre are also of frequent occurrence, while they are rare in other fibres used for paper. Bundles of fibres are rarely met

with, whereas they frequently occur in jute and less frequently in Manila fibres.

SANSEVIERA FIBRES. BOWSTRING HEMP.

Source.—The leaf fibres of several species of *Sansevieria*, a genus of plants belonging to the *Liliaceæ*, are used for technical purposes, such as cordage, the strings of bows (whence the name *bowstring hemp*), and mats, though most of them are unsuitable for textile fabrics.

Most of these species are found in Africa, while others grow wild or are cultivated in India, Ceylon and tropical America.

One of the best-known species is *S. guineensis*, which yields the fibre known as *African bowstring hemp*. It is largely cultivated in Guinea, and more recently in other parts of Africa.

The so-called *Pangane hemp* is derived from *S. Kirkii*, which grows in Pangane in South East Africa; while *Florida bowstring hemp* is the product of *S. longiflora*, which is cultivated in South Carolina and in South Africa.

The Indian species *S. roxburghiana* yields the true *bowstring hemp*, while a shorter fibre is separated from *S. zeylanica* in Ceylon.

The so-called *Ifé hemp*, obtained from a South African species, *S. cylindrica*, is used for marine cordage.

The fibre is separated from the leaf either by direct mechanical treatment, usually of a manual kind, or after a sort of preliminary retting, but the latter fibre is coarser and not so strong.

The length of the commercial fibre varies considerably with the species of *Sansevieria* that produced it.

Wiesner,¹ quoting from Preyer, gives the length of the fibres from *S. longiflora* as up to 14 metres and those of *S. zeylanica* as reaching 1 metre.

Specimens of various origin examined at the Imperial Institute had staples from 1.5 to 3 or 4 feet in length.

According to Matthews,² sansevieria fibres range from 2 to 9 feet in length.

¹ *Loc. cit.*, p. 400.

² *Loc. cit.*, p. 329.

The best grades are white or of a light brown tint, while inferior sorts are darker in colour.

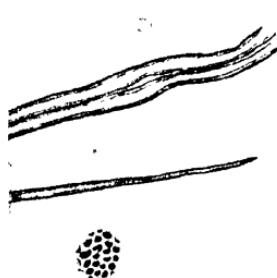


FIG. 58.—Fibres of *Sansevieria Guineensis*.

the fibres to be hollow.

According to Grailach the bast cells range from 2.8 to 3.2 mm. in length, and have a diameter of 18 to 36 μ .

Characteristic spiral cells of parenchymatous tissue may be observed, but stegmata are not present.

The walls of the fibre cells give the reactions for cellulose, but other parts give the lignone reactions.

Samples of sansevieria fibre examined at the Imperial Institute¹ gave the following results:—

	"Tuor" Fibre (<i>S. guineensis</i>)	<i>S. guineensis</i> from Fiji from Africa.	<i>S. guineensis</i> from Sierra Leone.	
			I	II (Unretted.)
Moisture	8.8	8.6	10.6	9.7
Ash	1.2	0.5	0.4	0.7
α -hydrolysis (loss)	12.4	9.1	8.9	10.8
β -hydrolysis (loss)	16.1	12.1	13.9	13.3
Acid purification (loss)	4.5	1.3	1.8	0.8
Cellulose	69.9	75.0	78.0	78.1

¹ "Bull. Imp. Inst.", 1907, 5, pp. 111, 223.

Specimens of *S. zeylanica* also gave the following results:—¹

Source of Fibre.	Moisture.	Ash.	Cellulose
	Per cent.	Per cent.	Per cent.
South Australia	8.1	0.4	80.0
Assam	9.4	0.7	75.6
Grenada	9.5	1.4	72.7
Straits Settlements	9.9	0.7	75.9

A specimen examined by the present writers contained 8.82 per cent. of moisture, 1.37 per cent. of ash, and 0.32 per cent. of phosphoric acid (P_2O_5).

SUNN HEMP

Of the numerous species of *Crotalaria* only few are cultivated for fibre, the best-known being *C. juncea*, *C. Burbia*, *C. retusa*, and *C. tenuifolia*, all of which are grown in India.

Sunn hemp, which derives its name from a native Indian word, is the bast fibre of *Crotalaria juncea*, which is cultivated throughout Southern Asia and especially in India and Java. Its value as a fibre has long been known, and references to its use are said to occur in Sanscrit literature.

It is also known as *kenna*, *Madras hemp*, *brown hemp*, and *Bombay hemp*, but the last two names are also given to the fibres of *Hibiscus cannabinus*.

The fibres are prepared in a similar way to hemp by a process of retting and hackling, and when carefully prepared form a very fine spinning material.

Sunn hemp is extensively used for ropes, the strength of which is from about a half to two-thirds that of Indian hemp ropes of the same dimensions (Royle).²

The fibre is very similar to ordinary hemp in appearance. It has a slight lustre like that of jute, which it also resembles in colour (pale yellow).

The fibre elements may be easily separated by treatment with chromic acid or sodium hydroxide solution.

¹ "Bull. Imp. Inst.," 1904, 2, p. 88.

² "Fibrous Plants of India."

The bast cells vary from 0.5 to 6.9 mm. in length and from about 20 to 42 μ in breadth (Wiesner).¹ Hanausek gives their breadth at 13 to 50 μ . They are thus among the broadest of known bast cells.

The ends of the bast cells have characteristic rounded ends. Those cells that have been treated with chromic acid show parallel stripes on the surface, while in the case of those treated with hot caustic alkali the markings are spiral.

The parenchymatous elements of the fibre consist of thin-walled cells usually about 32 μ in length by about 22 μ in diameter (Wiesner).

In cross-section the different cells are seen to be separated by a median layer. The lumen is much wider than in the case of hemp and also contains a yellowish substance which is absent from hemp.

According to Wiesner no other plant fibre possesses so low an amount of moisture, a characteristic which is an advantage for spinning. Thus a specimen of the air-dried fibre examined by him contained only 5.34 per cent. of moisture, which became 10.87 per cent. after exposure to an atmosphere saturated with steam.

Fibres that have been stored for some time, however, show a higher percentage of moisture.

The amount of ash is also low, and does not show any crystals. A specimen of the dried fibre examined by Wiesner yielded 0.99 per cent. of ash.

The following analysis of a sample of sunn hemp is given by Muller: Moisture, 9.60; ash, 0.61; aqueous extract, 2.82; fat and wax, 0.55; cellulose, 80.01; and pectin substances, 6.41 per cent.

Cross and Bevan² give the following analytical values obtained in the examination of a sample of Indian sunn hemp: Water, 8.5; ash, 1.4; α -hydrolysis (loss), 8.3; β -hydrolysis (loss), 11.7; acid purification (loss), 2.7; and cellulose, 83.0 per cent.

Notwithstanding its yellow colour sunn hemp fibre is only

¹ *Loc. cit.*, p. 313.

² "Indian Fibres," p. 9.

slightly lignified, but the outer portions of the bast cells are strongly lignified (von Höhnel).

Aniline sulphate imparts to them a faint yellow coloration, and phloroglucinol with hydrochloric acid a very faint violet colour.

Iodine colours them yellow and iodine with sulphuric acid gives a red colour.

When treated with cuprainingonium solution the fibres turn blue and swell up, and are eventually dissolved.

GAMBO HEMP.

The fibre known commercially as *gambo* or *ambari hemp* is obtained from the Indian plant *Hibiscus cannabinus*, which has long been cultivated for this purpose in India and the West Indies, and more recently in other tropical countries.

The fibres are irregular in length and thickness which Wiesner¹ attributes to faulty methods of separation.

The finest fibres may be not more than a few inches in length, while the coarser ones may reach 5 or 6 feet, and have a diameter of 40 to 150 μ .

The colour varies from dirty white to yellowish-grey.

In microscopical characteristics gambo hemp resembles jute. The fibre elements may readily be separated by treatment with chromic acid or potassium hydroxide solution. The finer fibres consists of bast cells (4 to 6 mm. in length and 20 to 41 μ in diameter), which give a blue coloration with iodine and sulphuric acid, while the coarser fibres contain also strongly lignified parenchyme cells, which give a brown coloration with the reagent. In cross section the fibre shows a narrow lumen and broad median layers between the cells.

The chemical reactions indicate a slight amount of lignification. Iodine gives a yellow coloration and on the addition of sulphuric acid the bast cells swell up and turn blue.

Aniline sulphate colours the fibre a faint yellow, and phloroglucinol and hydrochloric acid impart a faint violet coloration to it.

¹ *Loc. cit.*, ii. p. 309.

Cuprammonium solution colours the fibre a pronounced blue, and slowly dissolves the bast cells, leaving the inner cell walls as an undissolved residue.

A specimen of air-dried fibre examined by Wiesner contained 7.38 per cent. of moisture, and yielded 2.55 per cent. of ash devoid of crystals.

Cross and Bevan¹ obtained the following results in the examination of an Indian sample of *Hibiscus* fibre: water, 10.6; ash, 2.2; α -hydrolysis (loss), 14.0; β -hydrolysis (loss), 19.5; and cellulose, 73 per cent.

Watt found that a sample of gambo hemp steamed for 2 hours under pressure, then boiled for 3 hours with water, and again steamed for 4 hours lost only 3.63 per cent. in weight; whereas under the same treatment flax lost 3.5 per cent.; Manila hemp, 6.07 per cent.; ordinary hemp, 6.18 to 8.44 per cent.; and jute, 21.39 per cent.

Gambo hemp is used in the manufacture of rope, and is also woven into a coarse fabric in India.

Hibiscus esculentus.—The fibre of *Hibiscus esculentus*, termed *okra*, is used for the same purposes as gambo hemp, and is also occasionally employed as an adulterant of jute, of which it has only ~~at~~ ^{but} two-thirds the strength.

NEW ZEALAND FLAX.

The leaves of the plant *Phormium tenax* furnish a fibre, which, from the fact of its being originally derived from New Zealand, is known as New Zealand flax.

The plant is also cultivated in Australia, and has been introduced into North America.

The leaves of the tree are from 3 to 6 feet in length, and several inches in breadth. The fibres are best separated by mechanical means only, since they are weakened by long-continued retting. The yield is usually about 12 to 14 per cent.

The best products are white or greyish or yellowish-white, and have a high lustre and great flexibility. According to

¹ "Indian Fibres," p. 9.

Royle the breaking strain of a specimen of New Zealand flax was 23.7 lb. as against 11.75 lb. for flax, and 16.75 lb. for hemp under parallel conditions.

Wiesner¹ states that the fibre consists in the main of bundles of bast fibres to which are attached parenchyme cells. The fibre elements, which may be separated by means of chromic acid or caustic alkali, vary from 2.7 to 5.65 mm. in length.

In cross section the bast cells appear loosely connected together. They are polygonal in outline and are usually about 13 μ in breadth.

The lumen is well marked, and fairly uniform in width.

The fibres themselves are very uniform in thickness and have a fairly smooth surface.

When treated with iodine and sulphuric acid New Zealand flax is coloured bright yellow, while aniline sulphate gives a similar coloration.

Cuprammonium solution decomposes the fibres, but the bast cells remain insoluble, and are therefore lignified. The separated bast cells give a red colour on treatment with nitric acid (Wiesner).

A specimen of New Zealand flax examined by Church had the following composition: Moisture, 11.61; ash, 0.63; gum and soluble substances, 21.99; fat, 1.08; pectin substances, 1.69; and cellulose, 63.0 per cent.

The fibre is mainly used in the manufacture of string and rope, while some of the finest products are also woven into cloth. It is also made into coarse mats, and in the United States is mixed with plaster into a fibrous material used for the walls of sheds and similar buildings.

MAURITIUS HEMP.

The commercial fibre, known as *Mauritius hemp*, is obtained from the leaves of *Furcraea gigantea*, a plant formerly classified among the agaves.

In addition to *F. gigantea*, which has been cultivated in Mauritius since about the middle of the eighteenth century, the

¹ *Loc. cit.*, p. 388.

fibres of other species of *Furcraea* are used by the natives in the tropical countries where they grow.

Thus *F. cubensis* is grown in the West Indies for its fibre, which is locally known as *cajun*.

The leaves of the *F. gigantea* range from one to three yards, in length and are picked every third year. The fibre is separated from them either by hand or machinery, and is subsequently dried and washed.

The commercial fibre closely resembles sisal hemp in appearance and properties, although it is somewhat weaker; it also has many points of resemblance to sansevieria fibre.¹

The fibre elements vary from about 1.3 to 3.7 mm. in length, and from 15 to 24 μ in breadth.

The lumen seen in cross section is frequently wider than the walls of the fibre. It differs in appearance from the lumen of sansevieria in that the polygonal sides are rounded instead of being sharp-angled as in the latter.

A sample of Mauritius hemp from Bangalore gave the following analytical results: ² Moisture, 9.3; ash, 2.1; α -hydrolysis (loss), 17.1; β -hydrolysis (loss), 23.9; acid purification (loss), 6.1; and cellulose, 70.3 per cent. Length of staple, 3.5 to 4.25 feet.

Specimens of Mauritius hemp of different origin gave the following analytical results:—³

<i>Furcraea Gigantea</i> from	British Central Africa.	South India.	Grenada.	Victoria.
Moisture	Per cent. 8.7	Per cent. 9.8	Per cent. 10.2	Per cent. 11.6
Ash	1.1	—	2.4	2.3
α -hydrolysis (loss)	10.0	12.4	14.9	13.0
β -hydrolysis (loss)	14.5	14.5	22.0	23.5
Acid purification (loss)	1.7	1.7	3.8	5.6
Cellulose	75.8	77.7	77.8	72.2 ^o
Length of ultimate fibre in mm.	2—5 (Av. 3.5)	2—5	1—5	1—3

¹ Wiesner, *loc. cit.*, ii. p. 385. ² "Bull. Imp. Inst.", 1906, 4, p. 23.

³ *Ibid.*, 1904, 2, 88; 1908, 6, 387.

YERCUM FIBRE.

Bast-Fibre of Calotropis Gigantea.

Many of the plants the seeds of which yield a vegetable down also contain bast fibres of technical importance. Thus the bast fibres of *Marsdenia tenacissima* have long been used in India for cordage and other purposes, under the name of *Jetee fibre*,¹ or *rajmahal hemp*.²

The best known fibre of this group, however, is probably that obtained from the plant *Calotropis gigantea*, which is common in China and India. In the latter country it is known as *yercum*, whence the commercial name of the fibre.

According to Wiesner³ the fibres are about 30 cm. in length, and vary from about 0·18 to 0·24 mm. in diameter. Small off-shoots, consisting of separated bast-cells, issue from them.

The colour of yercum fibre is yellowish-white and the surface is moderately lustrous. A sample examined by Wiesner contained 5·67 per cent. of moisture, increasing to 13·48 per cent. in an atmosphere saturated with steam, and yielded, on ignition, 1·30 per cent. of ash.

Examined under the microscope the fibre is seen to be made up of bast and parenchyme cells. The former vary from 0·7 to 3 cm. in length by about 18 to 25 μ in diameter. They give a blue coloration with iodine and sulphuric acid, and are rapidly dissolved by cuprammonium solution.

The parenchyme cells have thin walls, and give a yellowish-green or yellow coloration with iodine and sulphuric acid.

A sample of Indian fibre examined by Cross and Bevan⁴ gave the following results: Moisture, 7·3; ash, 2·5; α -hydrolysis (loss), 13·0; β -hydrolysis (loss), 17·6; cellulose, 76·5; and acid purification (loss), 8·5 per cent.

PINE APPLE FIBRE.

The fibres from the leaves of the pine apple, *Ananassa sativa*, also known as *silk-grass*, are exceedingly fine, strong, and flexible,

¹ Royle, *loc. cit.*, p. 302.

² *Loc. cit.*, ii. p. 316.

³ Dodge, *loc. cit.*; p. 235.

⁴ "Indian Fibres," p. 9.

and have a fine silken lustre. The plant is supposed to be indigenous to South America, and is found wild in Mexico and Brazil. It is now extensively cultivated in tropical and semi-tropical countries, notably in the Bahamas, Fiji, Singapore and Natal.

In the Philippine Islands pine apple fibres are woven into a delicate fabric known as *piña cloth*, and in admixture with silk into a product termed *jusi*. These fabrics are stated to be impervious to water.

According to v. Hohnel¹ pine apple fibre differs from other monocotyledonous fibres in the remarkable fineness of its sclerenchyma (bast fibre) elements. These range from 3 to 9 mm. in length with an average of 5 mm., and from 4 to 8μ in diameter with an average of 6μ .

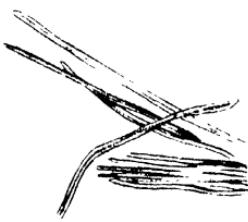


FIG. 59.—Pine Apple Fibres.

The lumen is extremely narrow, so that it appears almost as a thin line. The cell wall is not lignified, but the thick median layer is strongly lignified.

Cross sections give a yellow or greenish coloration with iodine and sulphuric acid.

A specimen of pine apple fibre examined at the Imperial Institute² consisted of soft white fibres about $3\frac{1}{2}$ feet in length. It gave the following analytical results: Moisture, 9.5; ash, 1.1; α -hydrolysis (loss), 13.7; β -hydrolysis (loss), 19.4; acid purification (loss), 1.7; and cellulose, 81.5 per cent.

¹ "Mikroskopie der Faserstoffe," p. 53.

² "Bull. Imp. Inst.," 1908, 6, p. 239.

CHAPTER X.

COCOANUT AND OTHER BRUSH FIBRES.

COCOANUT FIBRE (COIR).

Source.—The commercial fibre, coir, consists of the fibrous layer covering the shell of the fruit of cocoanut palm, *Cocos nucifera*, which is cultivated in most tropical countries.

There are numerous varieties of *C. nucifera*, but only a few such as *C. nucifera* var. *rutila* and var. *stupposa* are sufficiently rich in the fibres to be used for this purpose. The variety *rutila* yields the best quality of coir, while that from the variety *stupposa* is stiffer, harsher, and of much less value.

In India cocoanut fibre has long been used for cordage, and as a filling and spinning material. It is exported to Europe and North America in large quantities and is used for matting, coarse ropes, and brushes.

The fibrous hulls are steeped in water, preferably river water, for several months, and the fibres then separated by beating the mass with wooden mallets. The greater the proportion of salts in the water the darker the colour of the coir.

According to Wiesner¹ 1000 kilos. of cocoanuts yield 45 to 60 kilos. of long fine fibres and 7·5 to 12·5 kilos. of short fibres

Machinery is now employed in many places to shorten the retting process and the subsequent separation, the fibres being passed through rollers and subsequently hackled.

The separated fibres are frequently bleached either by exposure to the sun, or by means of chemical agents such as sulphur dioxide.

Characteristics.—The crude fibre varies in length from about

¹ *Loc. cit.*, p. 420.

15 to 33 cm. and in diameter from 50 to 300 μ (Wiesner). It is stiff and elastic, and resembles horse hair in appearance. The colour of the unbleached fibre is a light or dark chestnut brown.

It is extremely resistant to water, and is therefore of value for marine cordage. According to Wright its strength as compared with hemp is as 224 : 190.

Examined under the microscope the fibre bundles frequently show numerous small oval siliceous stegmata. By treating the fibre with nitric acid and then igniting it the siliceous contents of the stegmata may be seen in the ash attached together to form a sort of chain.

The cross section is oval. The cell wall is irregular in thickness, and the lumen is therefore irregular in form.

The ultimate fibre elements are about 0.5 to 1 mm. in length and 12 to 24 μ in thickness.

Wiesner (loc. cit.) found a specimen of the air-dried fibre to contain 11.28 per cent. of moisture, rising, after exposure to an atmosphere saturated with steam, to 17.99 per cent. The dry fibre yielded 1.49 per cent. of ash consisting largely of siliceous matter from the stegmata.

A commercial sample examined by the present writers contained 9.93 per cent. of moisture and yielded 1.32 per cent. of ash, in which was 0.23 per cent. of phosphoric acid (calculated as P_2O_5 on the air-dried fibres).

On repeated extraction with water this fibre yielded 2.69 per cent. of soluble substances.

Coir gives the distinctive reactions for lignocellulose, viz. bright yellow colorations with iodine and sulphuric acid, and with aniline sulphate.

IXTLE FIBRE.

Origin.—*Ixtle* or *istle* fibre is the name given to a product obtained from the leaves of *Agave heteracantha*, which grows



FIG. 60.—Portion of Cross-section through Cocoonut Fibre.

abundantly in the mountainous districts of Mexico, in Texas and in South California.

In commerce it is also known as *Tampico hemp* or *Mexican fibre*, and is sold in large quantities for the manufacture of cheap nail-brushes, and, in admixture with animal bristles, for other brushes.

The leaves of the plant, termed *lechuguilla* by the natives, are broad at the base and taper to a fine sharp point, and have serrated spiny edges.

The structural fibres are usually separated from the leaves by primitive methods, the pulp being scraped away by hand, and the residual fibre-bundles washed, dried in the sun, and combed with wooden combs. In the chief centres of the industry, however, Tamaulipas and San Luis Potosi, machinery is now employed for the separation.

The commercial fibre measures from 12 to 30 inches in length and is coarse, harsh, and resembling bristle in appearance. It thus differs considerably from the fine long *pita* fibre, which has also frequently been termed *ixtle fibre*.

The colour is canary-yellow, but on boiling the fibre with water the colouring matter is almost completely extracted.

The separated parenchymatous tissue of the plant is used as a substitute for soap, and even the commercial fibre yields a frothy solution when boiled with water.

In Mexico ixtle is used not only for brushes, but is also made into rope, and woven into coarse sacks used for carrying ore in the mines.

PIASSAVA.

The original piassava fibre was obtained from the leaves of the piassava palm, of Brazil, where it has long been used for



FIG. 61.—Thickened Ixtle Fibres, and Cross-section of the same.

ropes, sails, mats, etc. It was first introduced into Europe early in the nineteenth century, and at the present time is used in large quantities in the manufacture of brushes, for which its flexibility renders it very suitable.

In commerce piassava fibre is known as *true* or *Brazilian piassava*, and *African piassava*, while fibres from the leaves of several other similar plants are frequently sold under the same name.

Brazilian Piassava.—This is separated from the leaves of *Attalea funifera*, and is exported from Brazil, and, to a less extent, from other South American countries.

The technical fibre may be as long as two yards, while it ranges from 0.8 to 3.5 mm. in breadth (Wiesner). Here and there its edges are sharp. The colour varies from light brown to chocolate brown, but is fairly uniform on individual fibres. The elasticity of Brazilian piassava is much greater than that of the African product, which is therefore of smaller value.

A cross section shows an aggregate of bundles of ultimate fibres, and this distinguishes it from African piassava which consists of only a single fibre.

The parenchyme elements form a sort of irregular network across the section.



FIG. 62.—Portion of Cross-section through a Fibre of Bahia Piassava.

FIG. 63.—Siliceous Stegmata from Ash of Piassava.

According to Wiesner,¹ the bast cells vary from 0.3 to 0.9 mm. in length, and the parenchyme cells average 75 μ in length and up to 25 μ in breadth.

Stegmata may be observed in the periphery, and on treat-

¹ "Rohstoffe des Pflanzenreiches," ii. p. 408.

ment with chromic acid their siliceous contents are left as characteristic star-formed bodies. They may also be found in the ash left on igniting the fibre.

Greilach found that air-dried piassava contained 9·26 per cent. of moisture, and that after exposure to an atmosphere saturated with steam the proportion had risen to 16·98 per cent.

Wiesner found the ash in a dried sample to be 0·506 per cent.

African Piassava.—This is derived from the leaves of the wine palm, *Raphia vinifera* (bass fibre), which is common in tropical Africa.

The chief supplies of the commercial fibre are obtained from the West Coast of Africa and from Liberia and German West Africa.

Wiesner gives the length as not exceeding 60 cm. and the breadth as 1 to 3 mm.

The colour varies from pale yellow to light brown, the darker tints being the most frequent.

In cross section the fibre is seen to consist of a single ultimate fibre, of semi-concentric form, surrounded by a deposit of bast. The inner bast fibres are short (510 μ long) and have a narrow lumen, while the outer bast fibres are about five times as long and have a wide lumen (Wiesner).

The stigmata resemble in form those from the Brazilian piassava, but are somewhat larger.

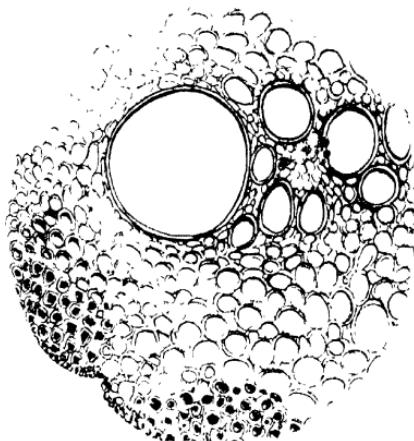


FIG. 64.—Cross-section through Fibre of African Piassava, showing Vascular Elements, Sclerenchyma Cells, etc.

In addition to these two fibres, the leaf fibres of other plants are also sold as piassava.

Of these the best known is *Borassus piassava* (*bassine*) from *Borassus flabellifer*, which grows in Ceylon. This is very similar to African piassava.

Another product known as *Caryota piassava* is obtained from *Caryota ureas*, which grows in India and Ceylon. In its appearance and properties it resembles *Tillandsia* fibre, and is also known commercially as *Kitol*. It is used as a "vegetable horse-hair".

The fibres termed *Dictyosperma piassava* are the product of a Madagascar plant.

CHAPTER XI.

VEGETABLE DOWNS AND UPHOLSTERY FIBRES.

FINE down resembling cotton or silk is formed in the seed capsules of numerous plants, notably those belonging to the *Bombaceæ*; but whereas in the case of cotton the hairs are attached to the seed itself, in the bombax cottons they have their origin in the inner wall of the capsule.

BOMBAX COTTONS.

The fine silky down produced by the so-called "cotton trees" is known by different names in its places of origin. Thus *paina limpa* is the product of *Bombaria heptaphyllum* of Brazil, while *ceiba* cotton is derived from *B. ceiba*, which grows in the West Indies and in tropical South America. The *wild Kapok* of East Africa is obtained from *B. rhodognaphon*, and the down of *B. malabaricum* is known in commerce as *Indian vegetable down*, *silk cotton*, *red cotton* and *semal cotton*.

Among other varieties may be mentioned *B. carolinum* of South America and *B. cumanensis* of Venezuela.

All these varieties of bombax cotton are closely similar, and it is practically impossible to differentiate them from one another.

They have all a fine silken appearance, but the fibres are weak, and have little elasticity. Hence they are of little value as textile materials, although in spite of this they are sometimes spun in admixture with cotton. Their chief commercial use is as stuffing material for upholstery, cushions and mattresses.

The fibres range in length from about 1 to 3 cm. According to Wiesner¹ those of *B. ceiba* average 1 to 1.5 cm. in length,

¹ "Rohstoffe des Pflanzenreiches," ii. p. 265.

those of *B. carolinum* 1 to 2 cm., and those of *B. heptaphyllum* 2 to 3 cm. The down of the last variety is also the strongest, and is, therefore, most frequently used for spinning.

The diameter at the widest point ranges from about 19 to 43 μ , the average being about 21 to 29 μ . The thickness of the cell wall compared with the inner diameter is 1:10, which explains its want of tenacity compared with cotton (4:10). The colour is rarely pure white (though *paina limpa* is fairly white) but ranges from yellow to brown.

The colouring matter, which is deposited in the cell membrane, is insoluble in water, acids or alkalies. It is darkened in the cell by ammonia. Cold nitric acid eventually decolorises the cell, causing the cell-wall to swell up (Wiesner).

The fibres are almost invariably single-celled and only occasionally do they contain two cells. They are usually cylindrical and taper gradually from the base to the point.

Examined under a magnification of 300 diameters the base usually appears swollen and shows a characteristic lace-like structure. Uninjured fibres are always straight; and show none of the characteristic twists of true cotton.

The cuticle is well-developed but is as a rule devoid of structure. In some cases, however, faint longitudinal markings may be seen.

KAPOK.

The commercial product known as *Kapok* was originally obtained from the seed capsules of *Eriodendron anfractuosum*, a plant growing in India, tropical Africa, South America and the East Indies. A large proportion is still derived from this source, though not infrequently a mixture of bombax cotton and kapok is sold under the same name.

Kapok is imported into Europe and used in large quantities for stuffing cushions and mattresses, and especially for life belts. In the compressed state it can support about 36 times its weight in water, and has the additional advantage over cork of drying quickly. It is also employed in surgery as a substitute for cotton wool.

It closely resembles the *bombax* cottons in its appearance, microscopical structure and chemical reactions.

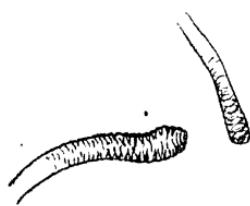


FIG. 65.—Kapok Fibres, showing Reticulated Structure of the Bulbous Base.

Like them it has a tapering cylindrical form usually consisting of a single cell with a bulbous base. It is lustrous and soft, but brittle and wanting in elasticity, and is therefore little suited for spinning. Examined under the microscope it appears as a smooth transparent almost structureless rod, usually broken and doubled over in one or more places.

Specimens of kapok from Lagos examined at the Imperial

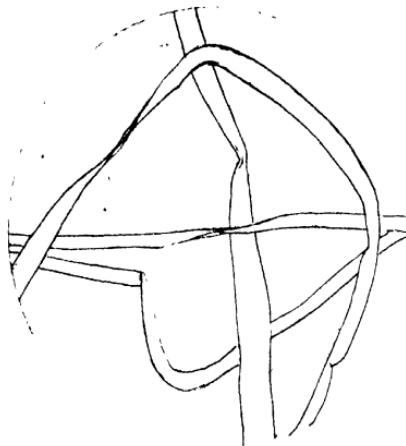


FIG. 66.—Kapok Fibres

Institute¹ were darker than the usual commercial fibre. Compared with samples from Java and the Seychelles they gave the following analytical results:—

¹ "Bull. Imp. Inst., 1907, 5, p. 120.

	Lagos Kapok. Per cent.	Java Kapok. Per cent.	Seychelles Kapok. Per cent.
Moisture	- - - 9.9	10.9	10.0
Ash	- - - 2.8	1.3	2.08
Cellulose	- - - 50.3	63.6	61.3

A commercial sample of kapok examined by the writers contained 8.74 per cent. of moisture, 2.95 per cent. of ash, and 0.22 per cent. of phosphoric acid (P_2O_5).

A specimen of Indian kapok examined by Cross and Bevan gave the following values: Moisture, 12.4; ash, 9.5; β -hydrolysis (loss), 50.5; cellulose, 33.6, and acid purification (loss), 6.5 per cent.

Kapok also resembles the bombax cottons in chemical composition. It contains lignocellulose, and therefore gives a yellow or yellowish-brown coloration with iodine and sulphuric acid.

Detection of Cotton in Kapok.—The last reaction affords a ready means of distinguishing kapok and bombax cottons from ordinary cotton, which gives a blue coloration with iodine and sulphuric acid.

Again, cotton gives only a faint violet coloration with phloroglucinol and hydrochloric acid, whereas kapok gives a red-violet coloration.

The following tests for differentiating cotton from kapok have been described by Greshoff:—¹

(i) Zinc chloride and iodine solution colours cotton reddish-blue, but gives a yellow colour to kapok.

(ii) On immersing the fibres for an hour in an alcoholic solution of magenta (0.01 grm. of dyestuff in 30 of alcohol and 30 of water), cotton is hardly affected, whereas kapok is dyed bright red.

When kapok is treated with Schweitzer's cuprammonium reagent it does not swell up and dissolve like cotton, but is but little affected.

For a quantitative estimation of cotton in kapok Greshoff recommends distillation of the material with hydrochloric acid,

¹ "Chem. Zentralbl.," 1908, ii. p. 642.

and precipitation with phloroglucinol of the furfural liberated from the pentosans.

The proportion of cotton may be calculated from the data that kapok contains 23 to 25 per cent. of pentosans and cotton about 3 per cent.

Down of *Ochroma Lagopus*.—The seed hairs of *Ochroma lagopus*, a plant indigenous to the West Indies and tropical South America, form the commercial product known as *édrédon végétale* or *patte du lièvre*.

The fibres, which it is practically impossible to distinguish with certainty from those of bombax cotton, consist of single cells of a somewhat dark colour.

They are about 0.5 to 1.5 cm. in length and 16 to 35 μ in diameter at the widest point. They do not always taper regularly to a point, but sometimes swell out about the middle, to contract again. The reticulated structures at the base are less pronounced than in the bombax cottons. The fibres also contain less lignocellulose.

Kumbi or Galgal.—The silken fibres from the seed capsules of *Cochlospermum gossypium* have long been used in India as a vegetable down for stuffing cushions, etc. Similar products are obtained from *Chlorisia speciosa* and *C. insignis* of South America. The fibres from the last-named plant have the property of swelling up when placed in water.

VEGETABLE SILK.

The seed hairs of certain plants are so much longer and stronger than those of bombax cottons and kapok that attempts have repeatedly been made to use them as a textile material. These downs are usually described as *vegetable silks*, although they appear to differ but little in chemical and physical properties from the other vegetable downs.

The best known *vegetable silks* are those produced by different varieties of *Asclepias*, by *Calotropis gigantea* and by *Beaumontia gigantea*.

Asclepias Cotton.—This is the silky down produced by the seeds of *Asclepias syriaca* indigenous to North America; by *A.*

curassavica and *A. volubilis*, which grow in South America and the West Indies; and by other plants belonging to the same genus. The fibres are soft and lustrous, but are too brittle for successful spinning. They are, however, occasionally used in admixture with cotton for yarn, and the so-called French "silver-cloth" is stated to consist of a mixture of wool with 20 per cent. of *asclepias* down.

According to Wiesner² fabrics consisting of a mixture of cotton and *asclepias* down are disintegrated the first time the article is washed.

The down is also unsatisfactory for gun-cotton since it burns too slowly and leaves too much ash.

Wiesner gives the following as the dimensions of the fibres of *A. curassavica*: Length, 1 to 3 cm. with an average of 2·5 cm.; maximum diameter, 20 to 40 μ ; average thickness of walls, 1·5 μ . There is considerable variation, however, in this thickness, which may sometimes attain one-third of that of the internal diameter of the fibre. This is due, as was first pointed out by von Hohnel, to the characteristic ridge-formations down the length of the fibre.

This formation affords a means of distinguishing between this vegetable silk and the bombax cottons.

It gives similar reactions to the latter with iodine and sulphuric acid and aniline sulphate, but the violet coloration with phloroglucinol and hydrochloric acid is of a duller shade.

Calotropis Gigantea.—This plant, found in India, the Moluccas, Venezuela, etc., produces a seed-down, which has a more pronounced yellow colour than that of *asclepias* cotton. In Venezuela it is the source of the commercial *algodon de seda*.

According to Wiesner² the fibres, which are single-cells, are 2 to 3 cm. in length, and have an average diameter of about 38 μ . The thickness of the cell-wall varies in the same fibre from about 1·4 to 4·2 μ .

This plant also produces a good bast fibre.

Beaumania Gigantea.—The seed-hairs of this plant, which

¹ *Loc. cit.*, ii. p. 296.

² *Loc. cit.*, p. 272.

is indigenous to India, are whiter and stronger than those of the other vegetable silks.

The fibres are 3 to 4.5 cm. in length by 35 to 50 μ in diameter, and the cell-wall averages about 3.9 μ in thickness (Wiesner).

The base is swollen up to a much greater extent than in the case of the fibres of *strophanthus* seeds, and thickened ridges may be seen in the cell-walls.

Other Vegetable Silks.—A species of *Strophanthus* growing in Senegal produces a very characteristic down, the hairs radiating at an angle of 45° from a central spindle rising from the seed. They are 5 to 6 cm. in length and 49 to 52 μ in diameter (Wiesner). The base is somewhat swollen, and small pores may be observed in the walls. The down is of a reddish-yellow tint and is not so lustrous as some of the other vegetable silks.

Vegetable silk is also produced by several varieties of *Marsdenia* growing in India.

Vegetable Wool.—A commercial product used as a filling material for mattresses, and occasionally spun in admixture with wool or cotton is sold under this name. It is manufactured from green fir cones, which are soaked and separated first by the action of bacteria and subsequently by means of machinery.

TILLANDSIA FIBRE.—VEGETABLE HORSEHAIR.

Several vegetable fibres have been sold under the name of *vegetable horsehair* as a filling material for mattresses, cushions, etc., but the fibre of *Tillandsia usneoides* most nearly resembles the animal product, both in appearance and in elasticity and durability.

The plant is a member of the *Bromeliaceae*, and grows as a parasite on trees in South America, Carolina, the West Indies, etc.

It has a branched and jointed stalk, and reaches a length of from one to three yards. It was first introduced into Europe in the eighteenth century, but it was only during the latter half of the last century that it became a regular article of commerce.

The crude product, which consists of the branched stems of

the plant, is of a grey or greenish-grey colour, and is covered with soft silvery grey scales. The diameter of the fibre ranges from about 0·3 to 0·5 mm. (Wiesner).¹

The commercial fibre consists either of the cut-up stems or of the stripped fibre.

According to von Höhnel² the fibre is composed of a layer of bast fibre, in which are embedded eight fibre bundles consisting of xylem and phloem. By treatment with potassium hydroxide this nucleus (the stripped fibre) is readily separated into its constituent parts.

The "purified" or "stripped" fibre has a jointed appearance. From the knots issue side branches which are also themselves frequently branched. Residual fragments of the epidermis may sometimes be found adhering to the surface.

According to Wiesner (loc. cit.) the commercial fibre never has natural ends. Its colour varies from brown to a lustrous black; occasionally it is artificially dyed. The diameter between the knots varies from 120 to 210 μ , and is usually about 150 to 160 μ .

A sample examined by Wiesner contained 9·0 per cent. of moisture (20·5 per cent. after exposure to air saturated with steam), and yielded 3·21 per cent. of ash (calculated on the dry substance). The ash was free from crystals.

The dark colour of the fibre interferes with colour reactions with iodine and with aniline sulphate. Cuprammonium solution is apparently without solvent action upon the fibre.

Lyxhayr is the commercial name of a vegetable substitute for horse hair, which is stated to be prepared from wood-fibre. It is extremely elastic and resilient, and judging by the results of practical tests over a long period, makes an admirable stuffing material for mattresses.

¹ *Loc. cit.*, n. p. 414.

² "Dinglers Polyt. J.," 1879, 234, pp. 407-10.

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